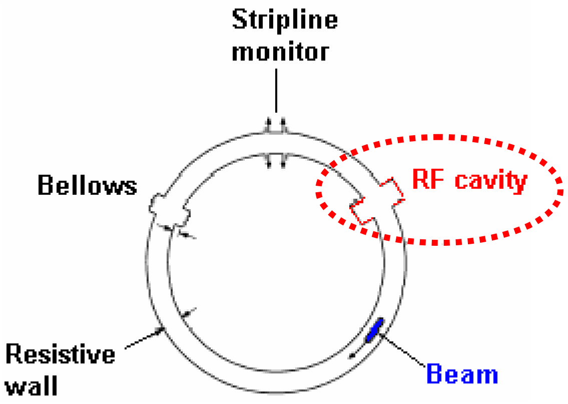
11th ESLS RF meeting – SOLEIL – October 4 & 5, 2007

HOM Damped Cavity for the ESRF

To increase the e-beam current in the Storage Ring up to 500 mA

ESRF / **R**ADIO **F**REQUENCY GROUP
Nicolas GUILLOTIN *(now at* SOLEIL SYNCHROTRON *)*
Jörn JACOB
Vincent SERRIÈRE

The **machine environment** is
seen by the bunch as a frequency dependent **impedance**
that can be sampled by the **beam spectral components**
[J.L Laclare; W. Chao; …]



Problem while increasing the beam current in the SR

⬇

Longitudinal Coupled Bunch Instabilities (LCBI)
driven by RF cavity Higher Order Modes (HOM)

To increase the e-beam current in the ESRF Storage Ring up to 500 mA, solutions could be for instance:

A) To attenuate the **<u>HOM Impedance</u>** *(above all the Longitudnal one)*

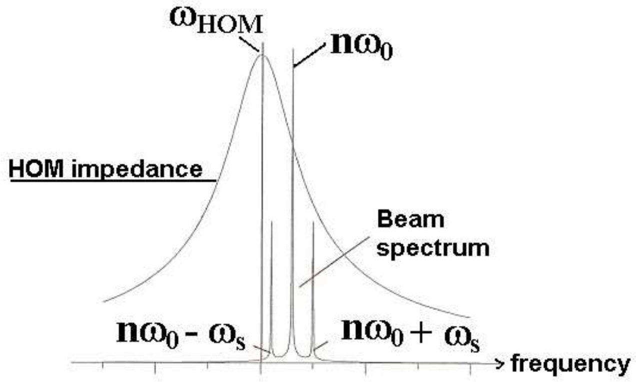
Instability threshold for Longitudinal impedance: $I_{th//}(\omega) = \frac{1}{\tau_{nat}} \cdot \frac{4\pi.Q_s.E_0/e}{\alpha_c.\omega.\boxed{Z_{//}(\omega)}.N_{cav}}$

Instability threshold for Transverse impedance: $I_{th\perp}(\omega) = \frac{1}{\tau_{\perp}} \cdot \frac{2.E_0/e}{\beta_{\perp}.f_0.\boxed{Z_{\perp}(\omega)}}$

Where $Z_{//}(\omega)$ and $Z_{\perp}(\omega)$ are the Narrow band Longitudinal and Transverse impedances related to cavity HOM.

B) Control of the **<u>HOM frequencies</u>** to avoid overlapping with synchrotron sidebands frequencies

Already used at the ESRF to reach a <u>maximum</u> current of <u>300 mA</u> if used with a complementary <u>feedback</u> system



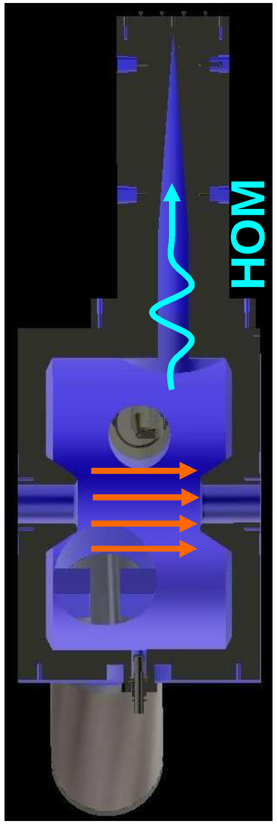
$f_{m,n,p} = p.Mf_o + n.f_o + m.f_s$ *(Eq.1)*

M = 992 at the ESRF
n = 0 to 991 (Coupled Bunch Mode number)
-inf < p < + inf
m refers to the bunch shape (m = 1, 2, 3 …)

First Investigated solution to reach an e-beam current of 0.5 Ampere in the ESRF Storage Ring without feedback system while fighting against the LCBI instabilities

Normal Conducting cavity with homogeneous cylindrical Ridge Waveguides loaded by ferrite to damp the HOM

[E. Weihreter, F. Marhauser *et al.* / *BESSY*]



FIRST LOW POWER PROTOTYPE

Development started in 2004,
Measurement finished in December 2006.

Cavity Body shape similar to the ‘EU’ model (500 MHz)

BESSY

國立清華大學
National Tsing Hua University
(NTHU)

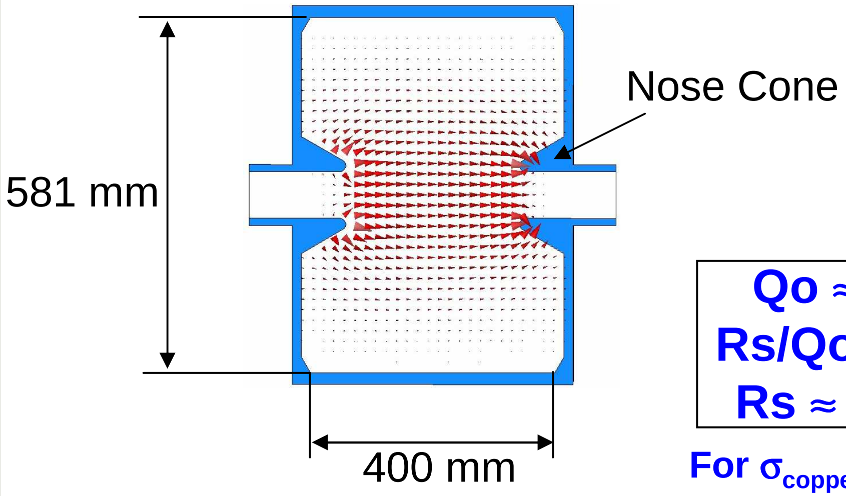
DELTA

SRS DARESBURY LABORATORY

MAX-lab

Simulation work

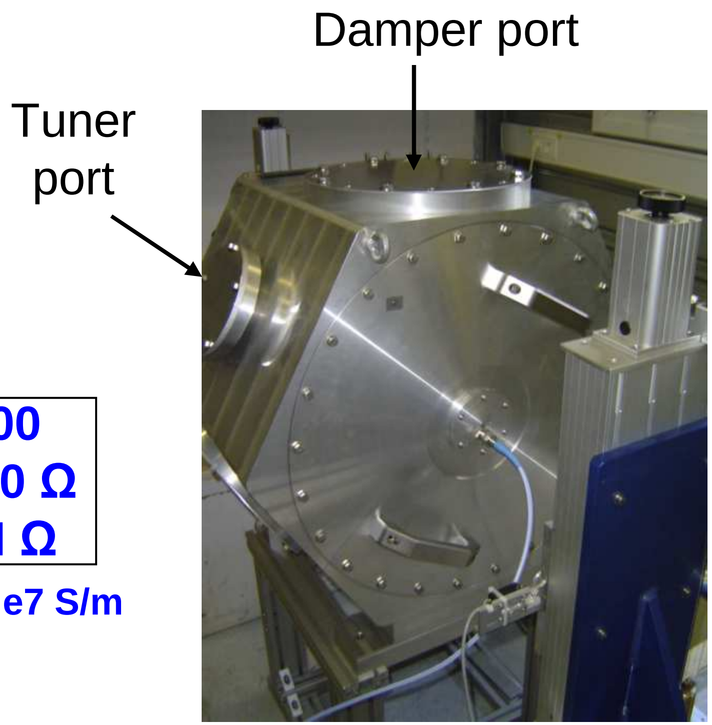
352.2 MHz for the ESRF



Red arrows:
TM_{010} electric field configuration

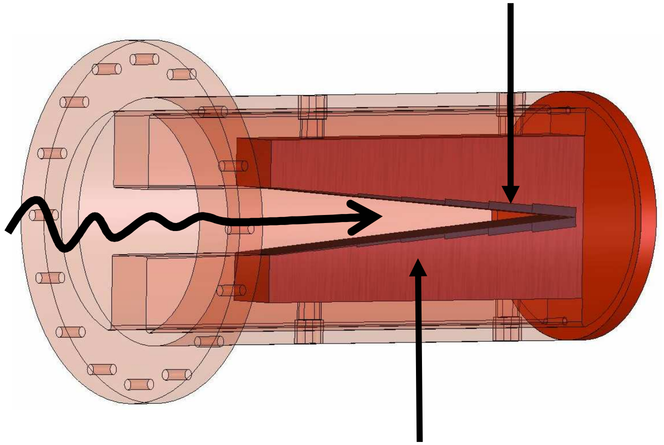
Qo ≈ 48000
Rs/Qo ≈ 150 Ω
Rs ≈ 7.2 M Ω

For σ_{copper} = 5.8 e7 S/m



Optimized Aluminium cavity body with ports.

Ferrite Loaded Double Ridge Waveguide (DRWG) as HOM damper adapted from the Willy-Wien model (BESSY)



Nickel-Zinc Ferrite C-48

Incident Waves (HOM)

Metallic Ridge

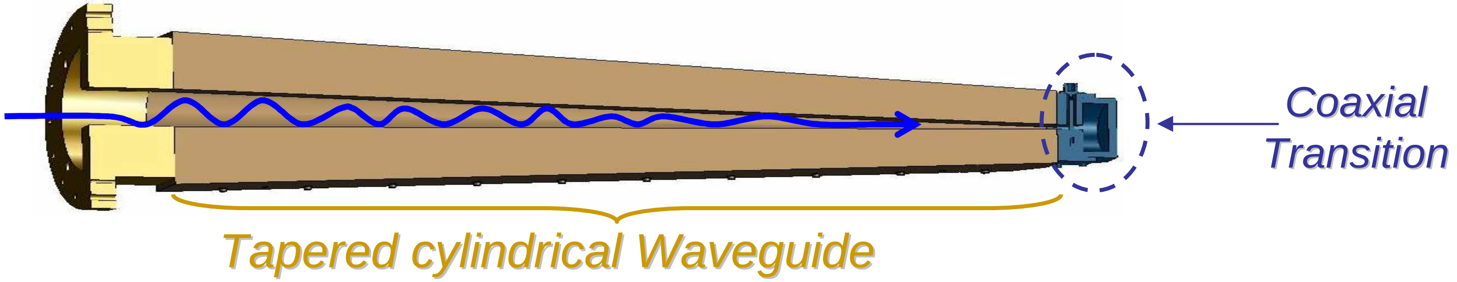
Optimized dimensions:

- Cut-off frequency TE_{11} mode: f_c = 430 MHz
- Inner diameter ∅ = 240 mm
- Distance between the two ridges d = 70 mm
- Width of the ridges w = 60 mm
- Ferrite length ≈ 400 mm

The cut-off freq is sufficiently high so that the accelerating mode at 352 MHz can not propagate to the loads but sufficiently low to let the HOM propagate

Cylindrical Waveguide to Coaxial Transition (CWCT):

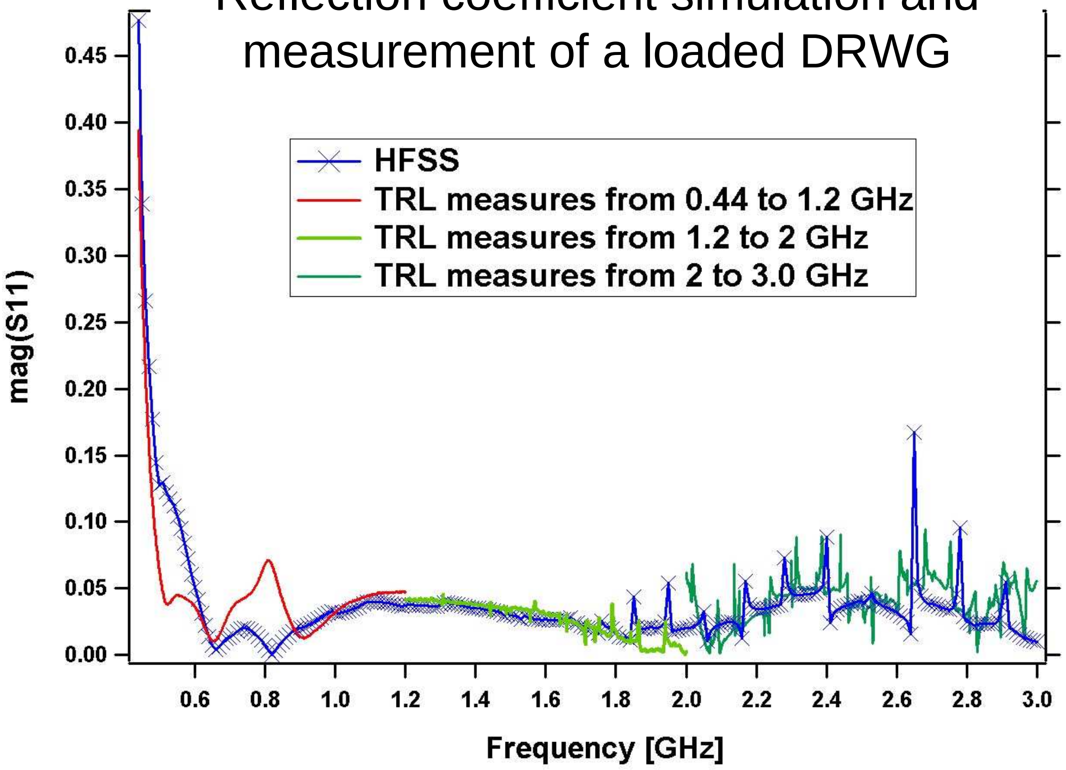
Based on the EU cavity CWCT model [BESSY (Germany) & NTHU (Taiwan)]

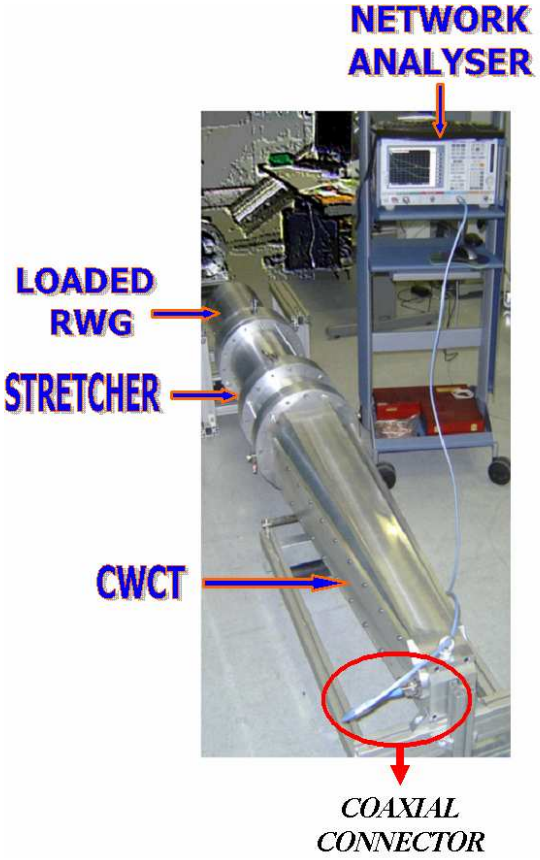


Coaxial Transition

Tapered cylindrical Waveguide

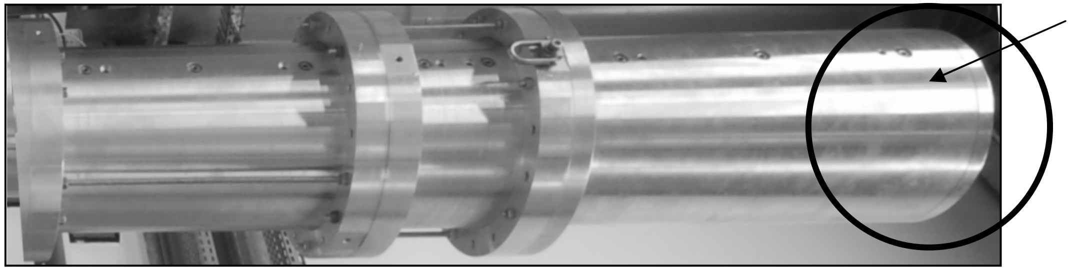
Reflection coefficient simulation and measurement of a loaded DRWG





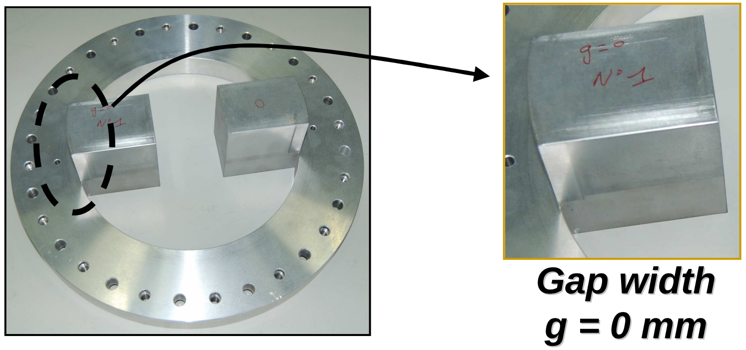
Mechanical tools to explore a maximum of cavity parameters:

- ✓ Stretchers for the Double Ridge Waveguides:

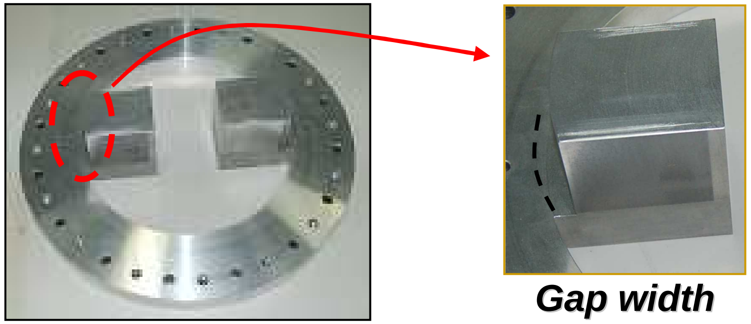


Ferrite loads at the top of the Dampers

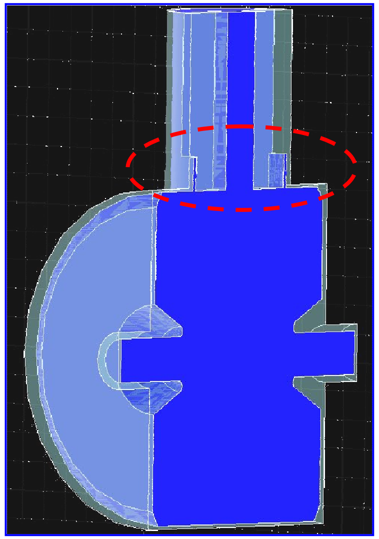
- ✓ ‘Coupling Sections’ with the so called ‘Gap’

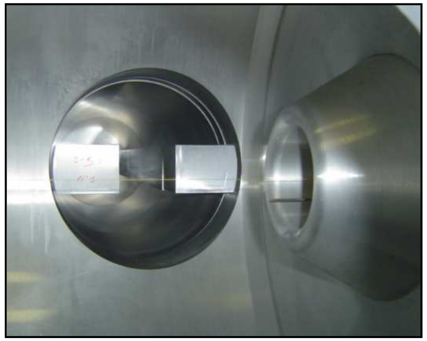


Gap width g = 0 mm

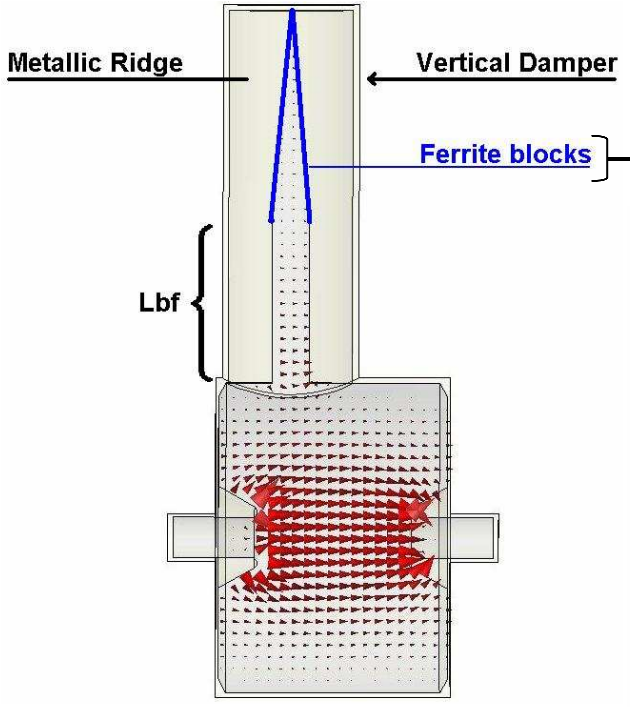


Gap width g = 5 mm

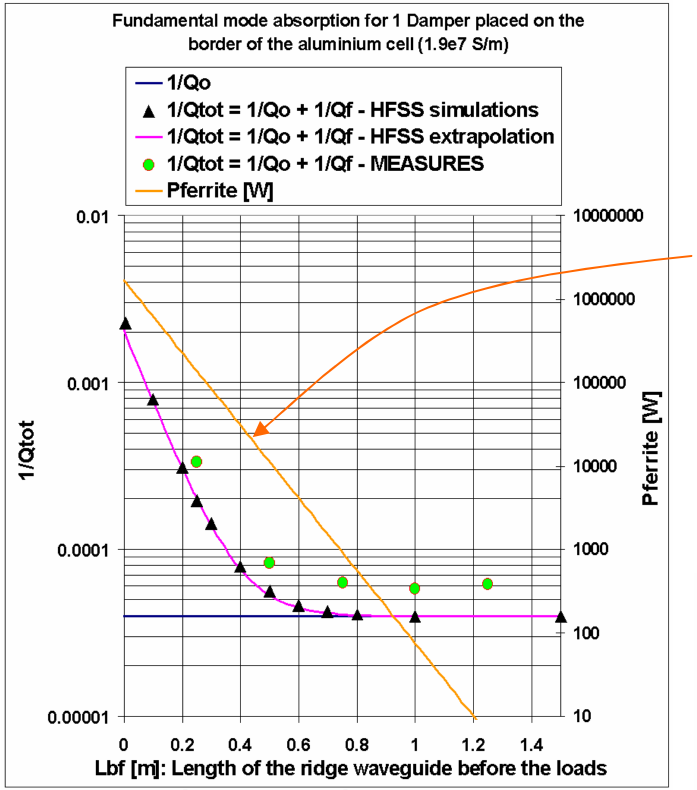




DRWG length effect on the Fundamental mode studied on a structure with one Damper only

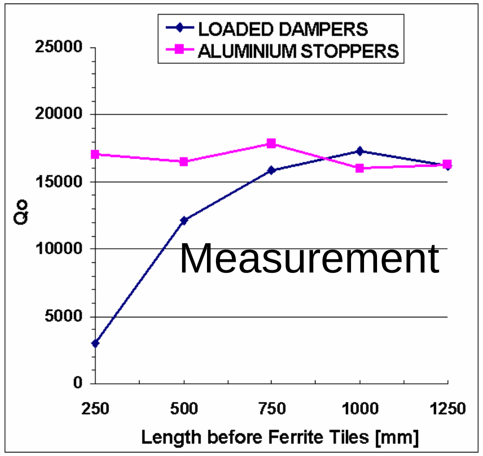


For the first load shape the *ferrite length* *was*
Lf ≈ 0.4 m



HFSS simu and measurement

Power from the Fundamental mode absorbed by the loads as a function of the length before ferrite



If the length before loads is shorter than ≈ 1 meter, then the Fundamental mode will be damped

Cavity with three Dampers

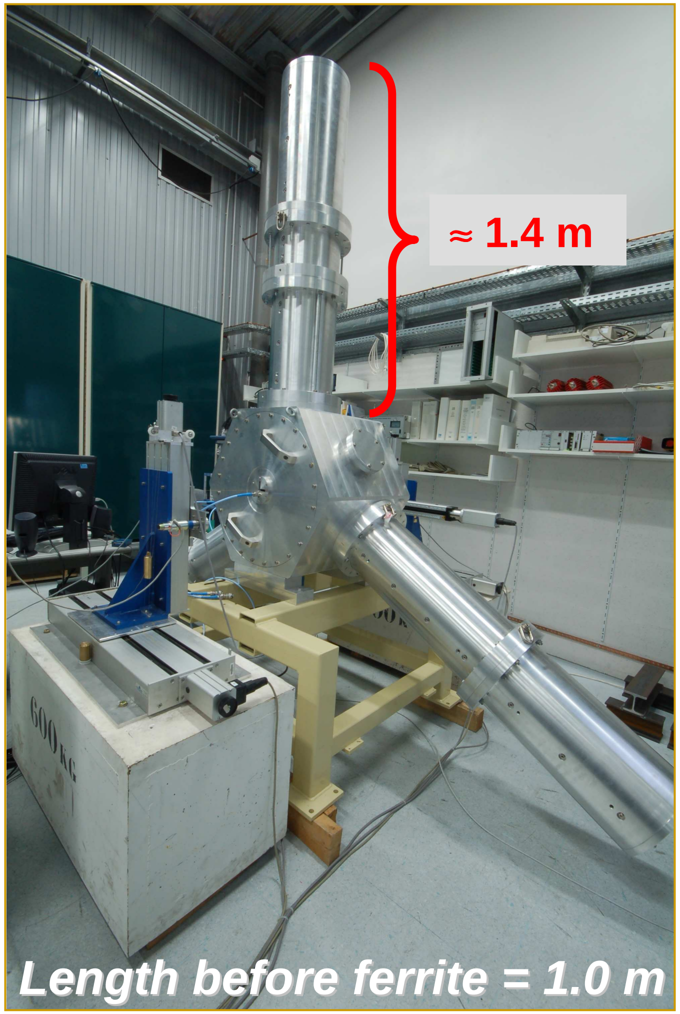
ESRF Proto 1
$f_r \approx$ 352.2 MHz

BESSY II
$f_r \approx$ 500 MHz

Scaling

$\xrightarrow{\hspace{2cm}}$

x ≈ 1.42



Fundamental mode study

Structure: Cavity Body + 3 Dampers + 3 coupling sections with g = 5 mm

($\sigma_{alu} \approx 1.9\ e7\ S/m$)

By measurement only:

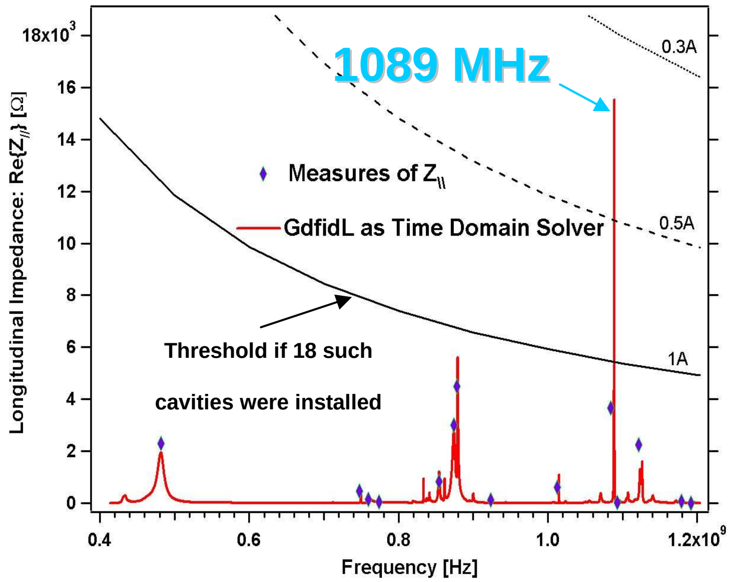
Qo ≈ 19000
Rs/Qo ≈ 146 Ω
Rs ≈ 2.8 M Ω

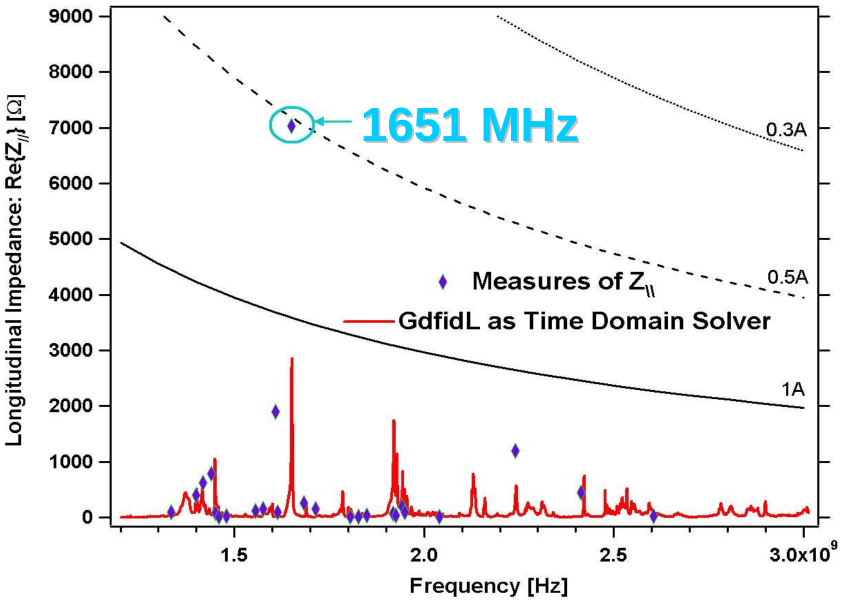
By extrapolation, for a copper prototype it could lead to:
Qo ≈ 33000 and Rs ≈ 4.2 M Ω
⇓
Acceptable performances

Remark:
HFSS => insufficient memory and very bad convergence for structures with long dampers including EM absorbing material like ferrite
GdfidL** => **unphysical results for long dampers

HOM longitudinal impedance measurement vs Time Domain (TD) simulations with GdfidL

Structure: Cavity Body + 3 Dampers + 3 coupling sections with g = 5 mm



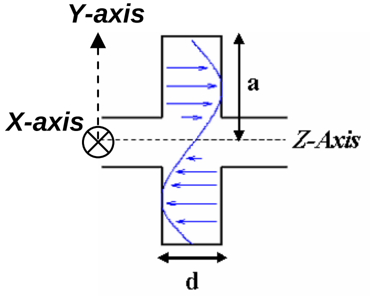


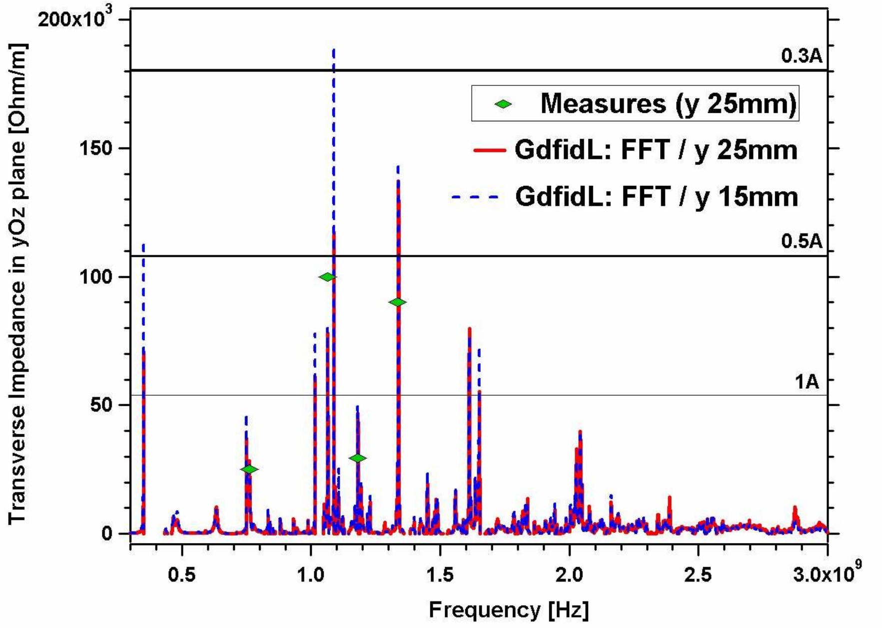
Strong discrepancy between simulations and measures for two modes:

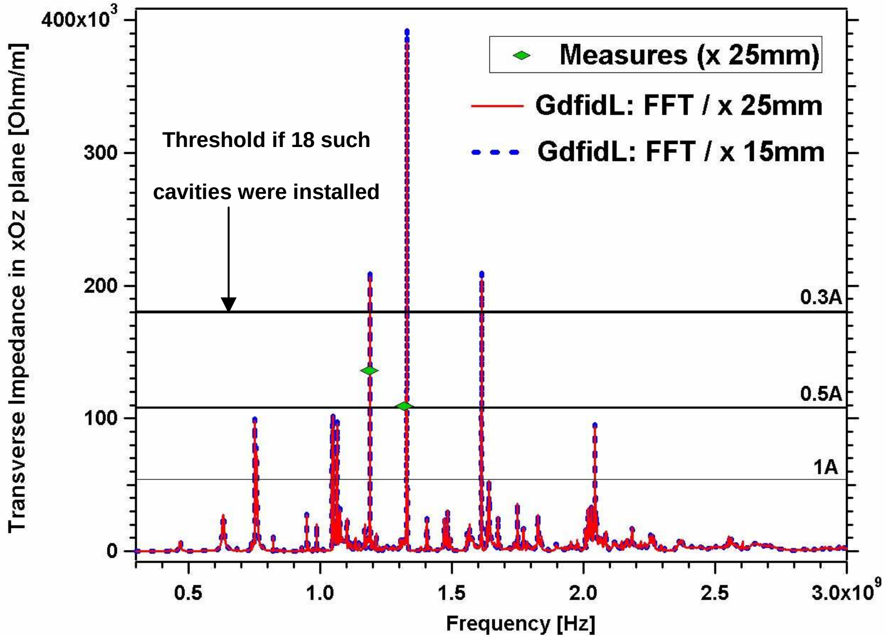
. At 1089 MHz it might be induced by simulation difficulties of the gap in the Coupling Sections

. At 1651 MHz … No particular explanation (it is neither the gap effect, nor a measurement error and the simulation meshing has no influence …)

HOM transverse impedance measurement vs Time Domain (TD) simulations with GdfidL



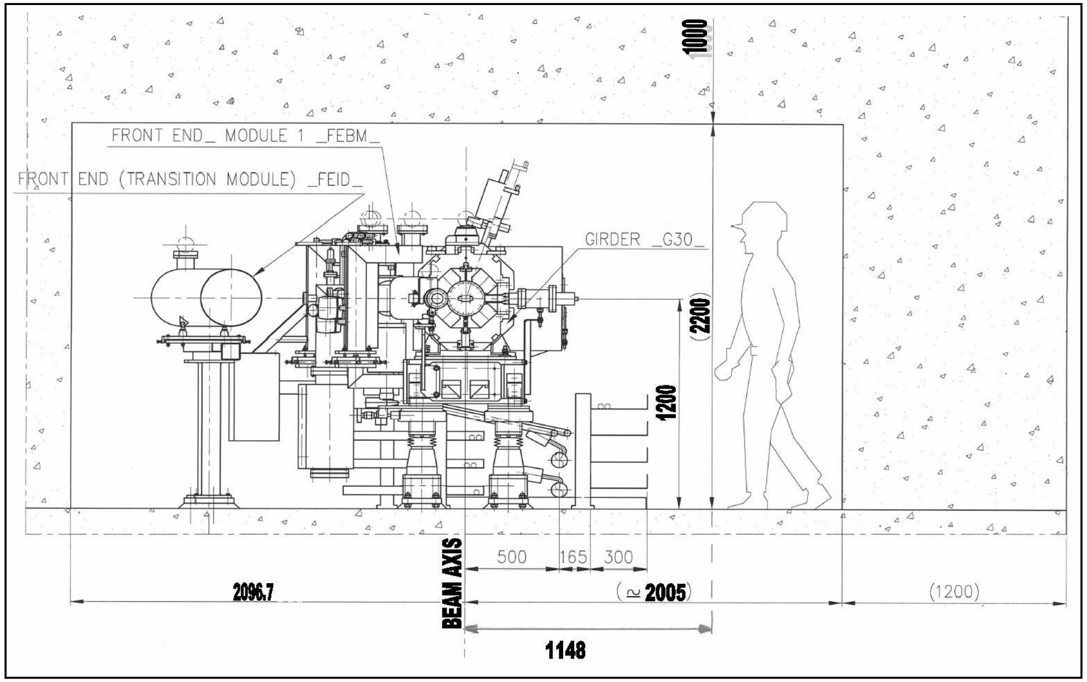




Red and blue curves refer to simulation results for two offsets of the line charge

Points which have been reconsidered for a second Prototype:

✓ Damper dimensions



✓ Ferrite shape: replace the Tiles ferrite with progressive varying thcikness by simple blocks of constant thickness (2.7 mm)

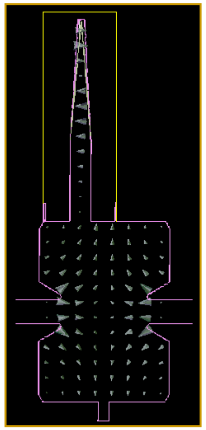
⇒ to take into account the brazing difficulties [cf Willy-Wien development]

✓ Improvement of the HOM damping

IMPROVED DESIGN
(2nd low power prototype)

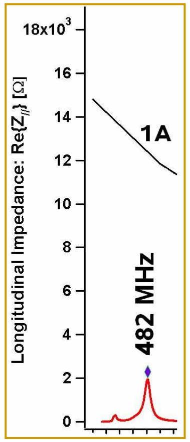
Development started in February 2007,
Measurement not yet started.

Development Strategy for the 2nd prototype



The TM_{011} mode at ≈ 482 MHz is the first mode with a potentially dangerous Longitudinal impedance

<u>But</u>: great margin compared to the threshold impedance contrary to the Willy-Wien cavity (Berlin)



✓ This TM_{011} mode is not very sensitive to the Dampers cut-off frequency f_c if:

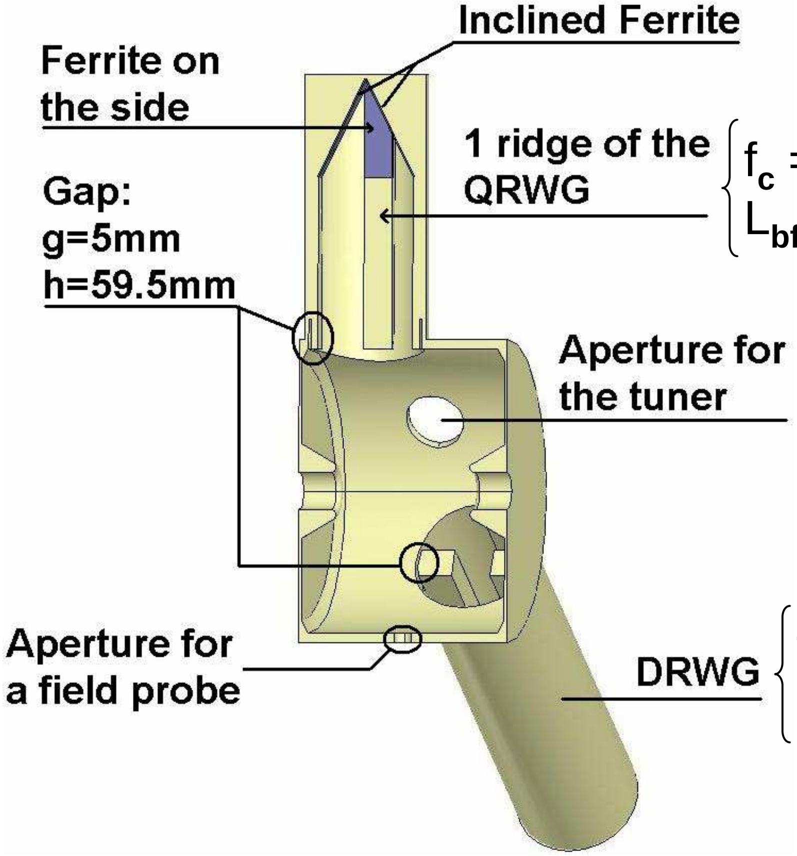
$$f_c < (f_{TM011} - 20\ \text{MHz})$$

⇒ **The Dampers cut-off frequency could be increased to 460 MHz leading to a possible reduction of the DRWG length**

✓ It has also been demonstrated for the first ESRF low power damped Prototype that only one loaded DRWG with f_c = 430 MHz was sufficient to damp the the TM_{011} mode below the threshold (contrary to the BESSY II cavity)

⇒ **At least one Damper can have a cut-off frequency far above the TM_{011} mode frequency**

Possible solution : ‘QUADRUPLE-ridge’ waveguide



Inclined Ferrite

Ferrite on the side

1 ridge of the QRWG

f_c = 749 MHz
L_{bf} = 0.35 m

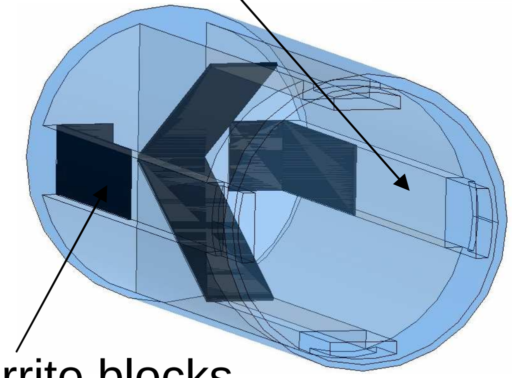
Gap:
g=5mm
h=59.5mm

Aperture for the tuner

Aperture for a field probe

DRWG

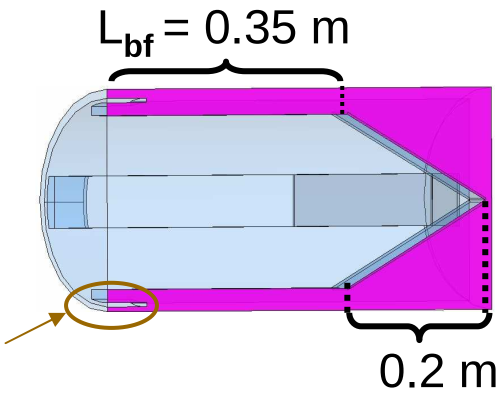
f_c = 460 MHz
L_{bf} = 0.74 m



Ridge

Ferrite blocks

Cut view



L_{bf} = 0.35 m

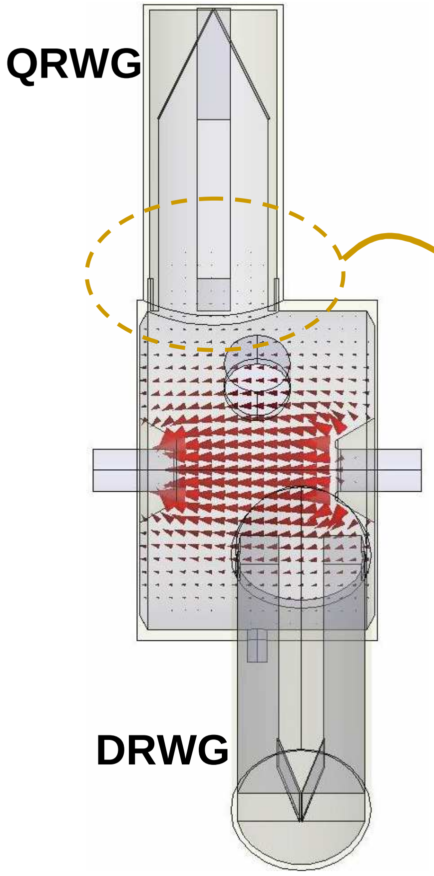
Gap g = 5 mm

0.2 m

Fundamental mode study

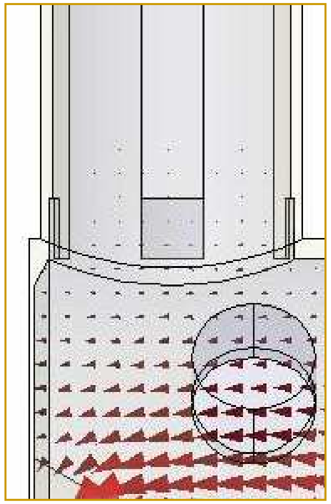
Structure: Cavity Body + 1 loaded 'Quad-RWG' + 2 inclined loaded DRWG + 3 coupling sections with g = 5 mm

$(\underline{\sigma_{copper} \approx 5.8\ e7\ S/m})$



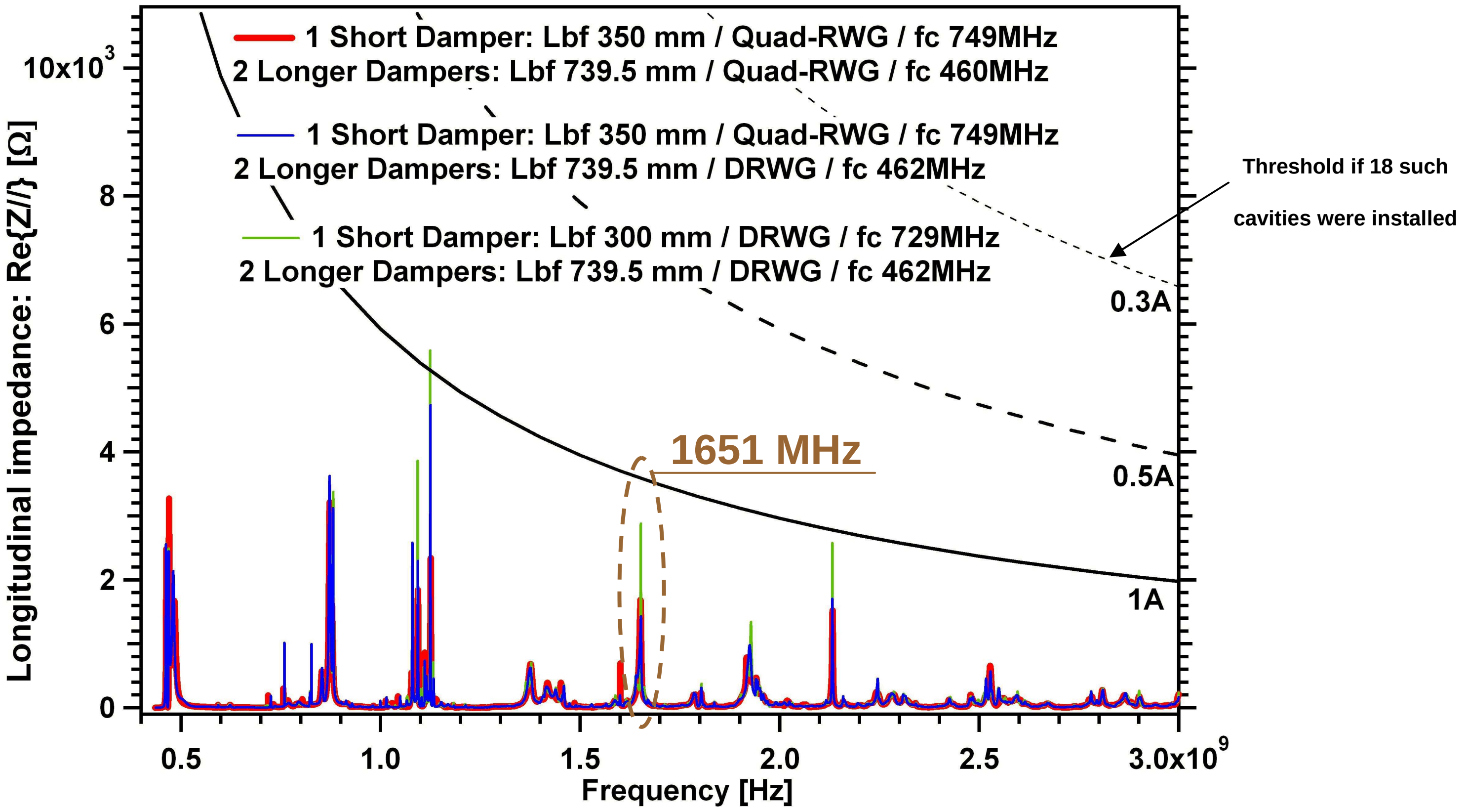
HFSS simulations only:

Qo ≈ 40500
Rs/Qo ≈ 147.7 Ω
Rs ≈ 5.98 M Ω → … *<u>If confirmed by measurement</u>*



Really no power absorbed from the accelerating mode since no propagation

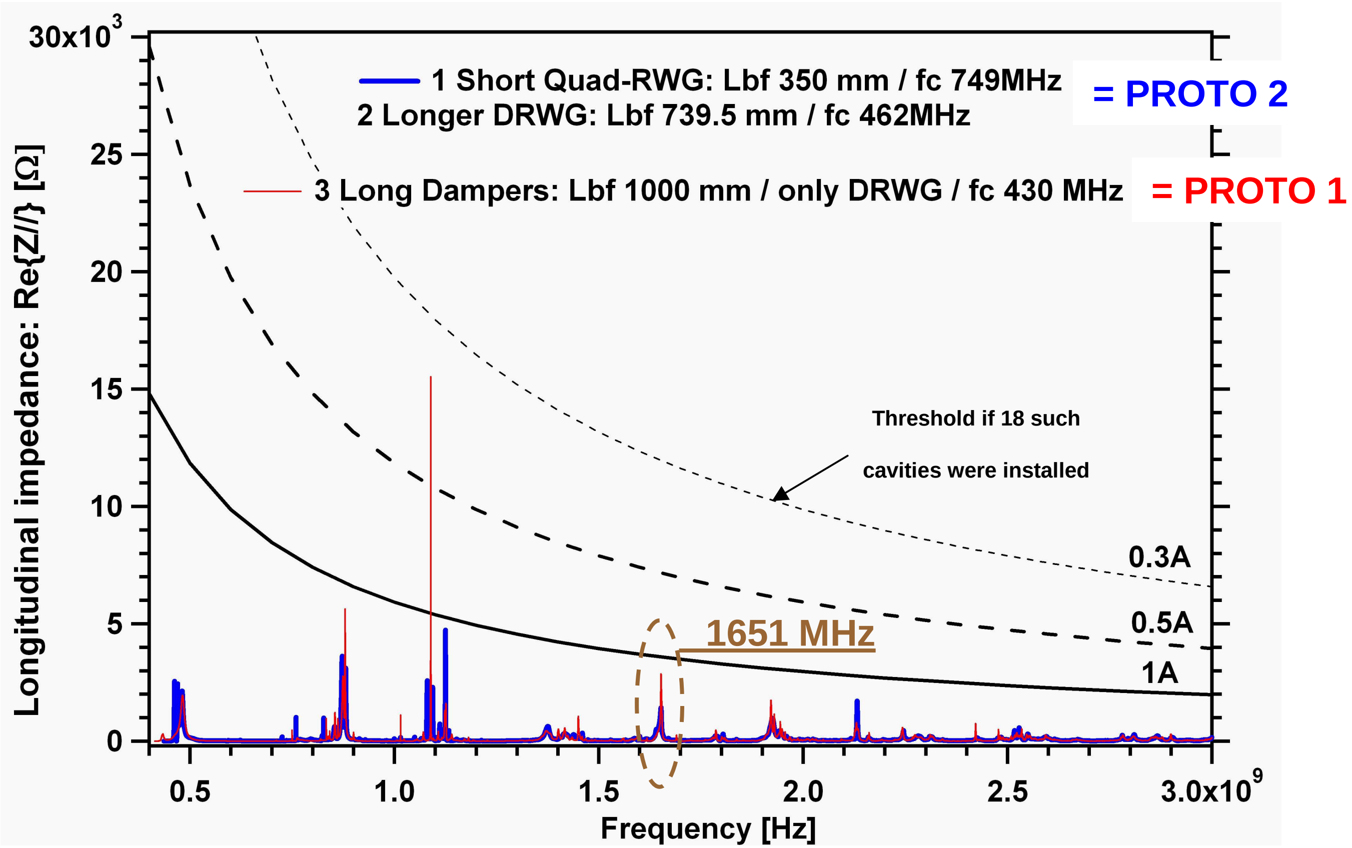
HOM longitudinal simulations in Time Domain with GdfidL (1)



Chosen solution: 1 short vertical Quad-Ridge Waveguide (QRWG) + 2 Longer Double Ridge Waveguides for manufacturing cost and vacuum quality considerations.

With 4 ridges the apertures to assure vacuum in the Dampers are more difficult to manage

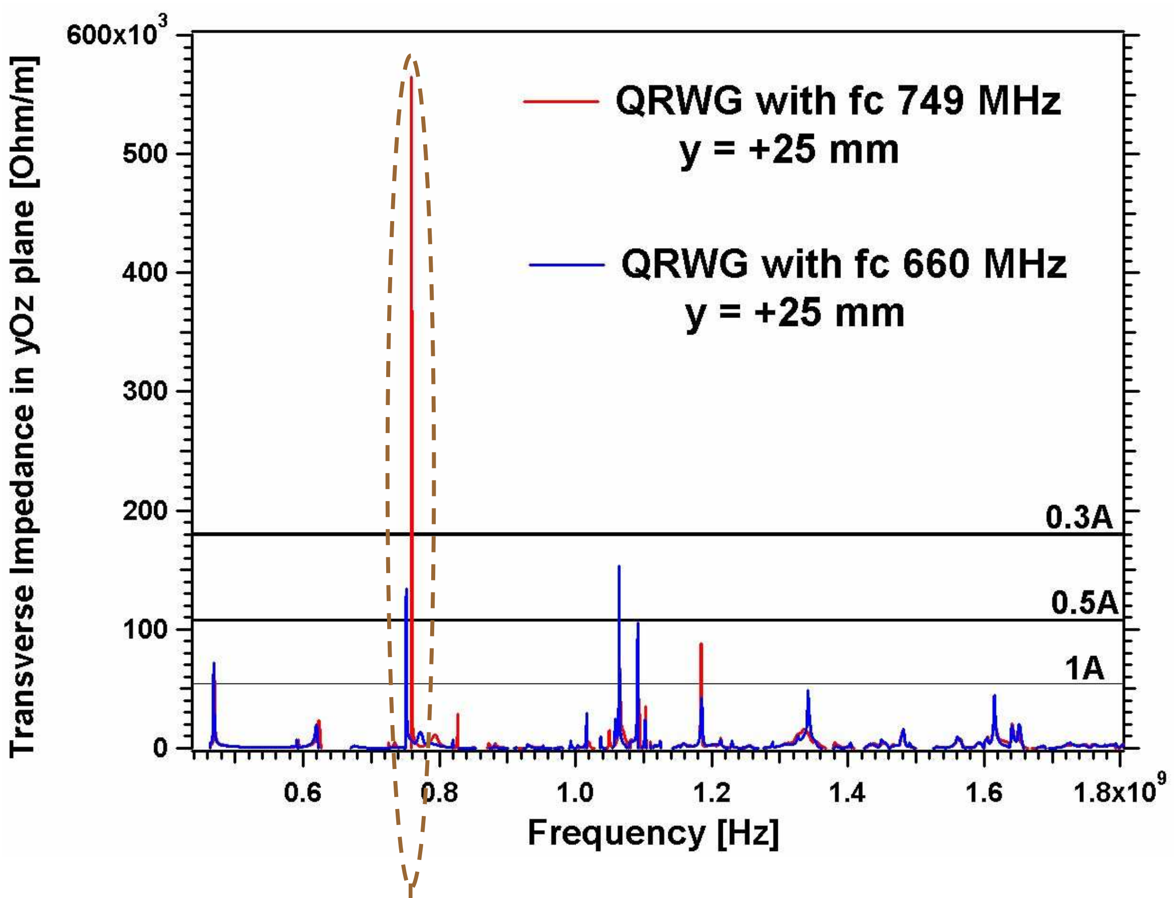
HOM longitudinal simulations in Time Domain with GdfidL (2)



By simulation the Longitudinal impedance of the mode at 1651 MHz is divided by two in the 2nd proto compared to the first structure

HOM transverse impedance simulations in Time Domain with GdfidL (1)

In yOz plane

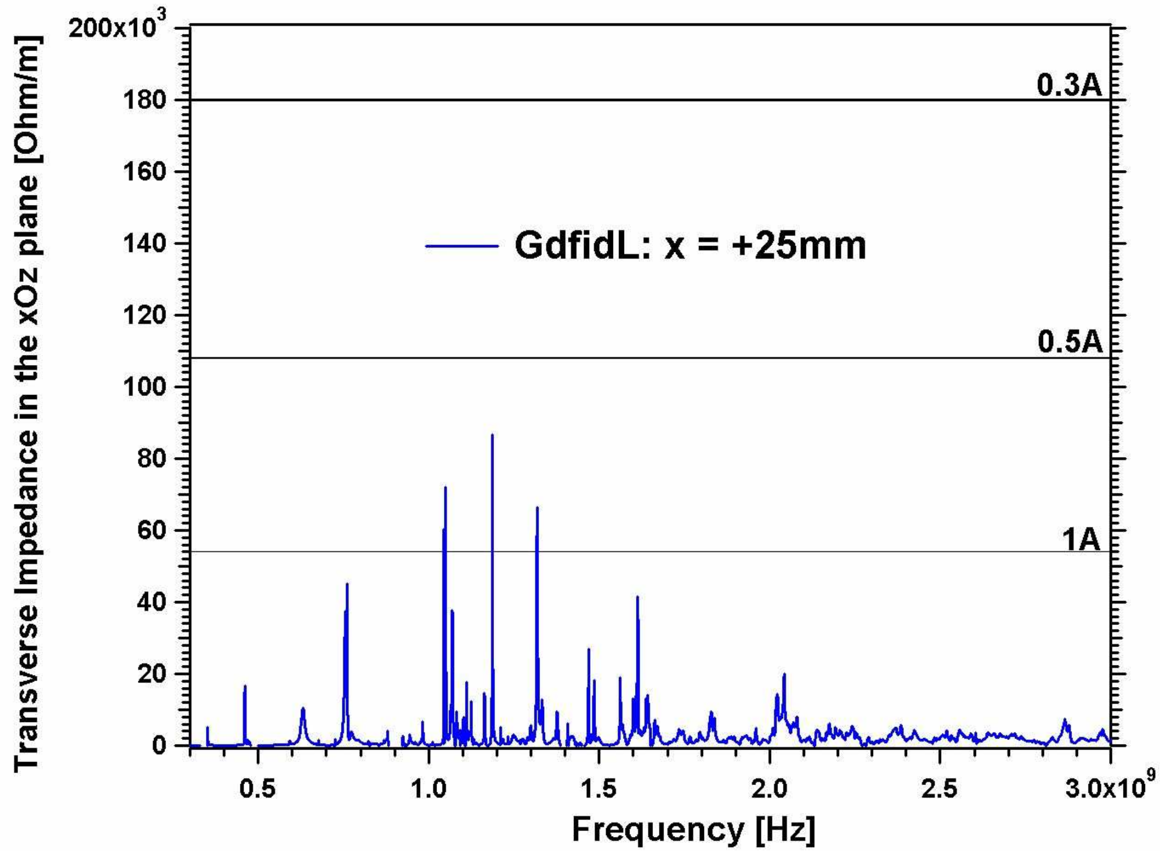


759 MHz

Might be related to the Quad-RWG cut-off frequency

HOM transverse impedance simulations in Time Domain with GdfidL (2)

In xOz plane



No particular problem up to 0.5 A

Modelling of LCBI cure at the ESRF based on ELETTRA cavity type

Principle

Control of the HOM frequency by cavity temperature tuning

$$\boxed{f_{HOM}(T, I_b) = f_{init_{HOM}} - K.\Delta T + H.[(f_{RF} - f_{RF0}) + \Delta BL(I_b)]}$$

K → Related to the thermal expansion of the copper structure

$f_{init_{HOM}}$ → Initial frequency of the considered HOM before temperature tuning

$f_{RF} - f_{RF0}$ → Fundamental mode frequency shift

$H.\Delta BL(I_b) = \Delta f_{BL}$ → Beam Loading compensation for the Fundamental mode

To avoid overlapping between the HOM frequencies with synchrotron sidebands frequencies near f_{LCBM}, above all for modes with high impedance

$$\boxed{Z_{//}(f_n) = \frac{(Rs_{//}/Q_0)_n . Q_{0n}}{1 + [Q_{0n}.(\frac{f_{LCBM\,n}}{f_{HOM\,n}} - \frac{f_{HOM\,n}}{f_{LCBM\,n}})]^2}}$$

Longitudinal impedance $Z_{//}(f_n)$ of the **Coupled Bunch Mode (CBM) number ‘n’**

When there is more than one bunch in a Storage Ring and the Q-value of the impedance is large enough then a bunch can still feel the wake fields created by the previous bunches whatever the resonant cavity

$\Downarrow$

HYPOTHESIS OF THE STUDY:

We add the impedance of the modes which have the same Coupled Bunch Mode number even if these modes are excited in different cavities

Simulation parameters have been based on SLS data concerning the cavity parameters

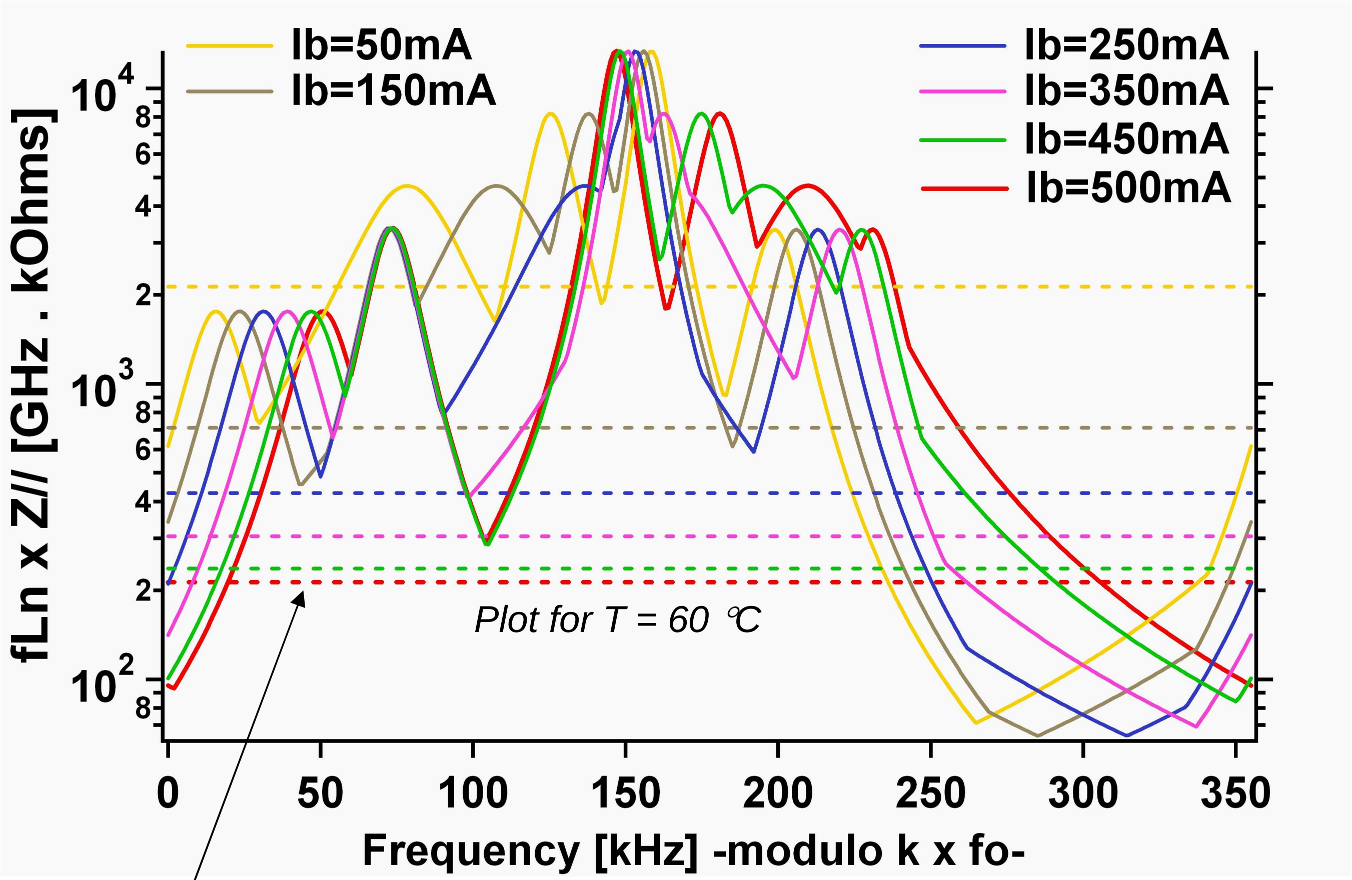
↓

Frequencies of the HOM, Quality Factors, Rs/Qo, thermal expansion coefficients etc, have been generated statistically so as to keep the same standard deviation of the parameter distribution as for the 4 measured SLS cavities

↓

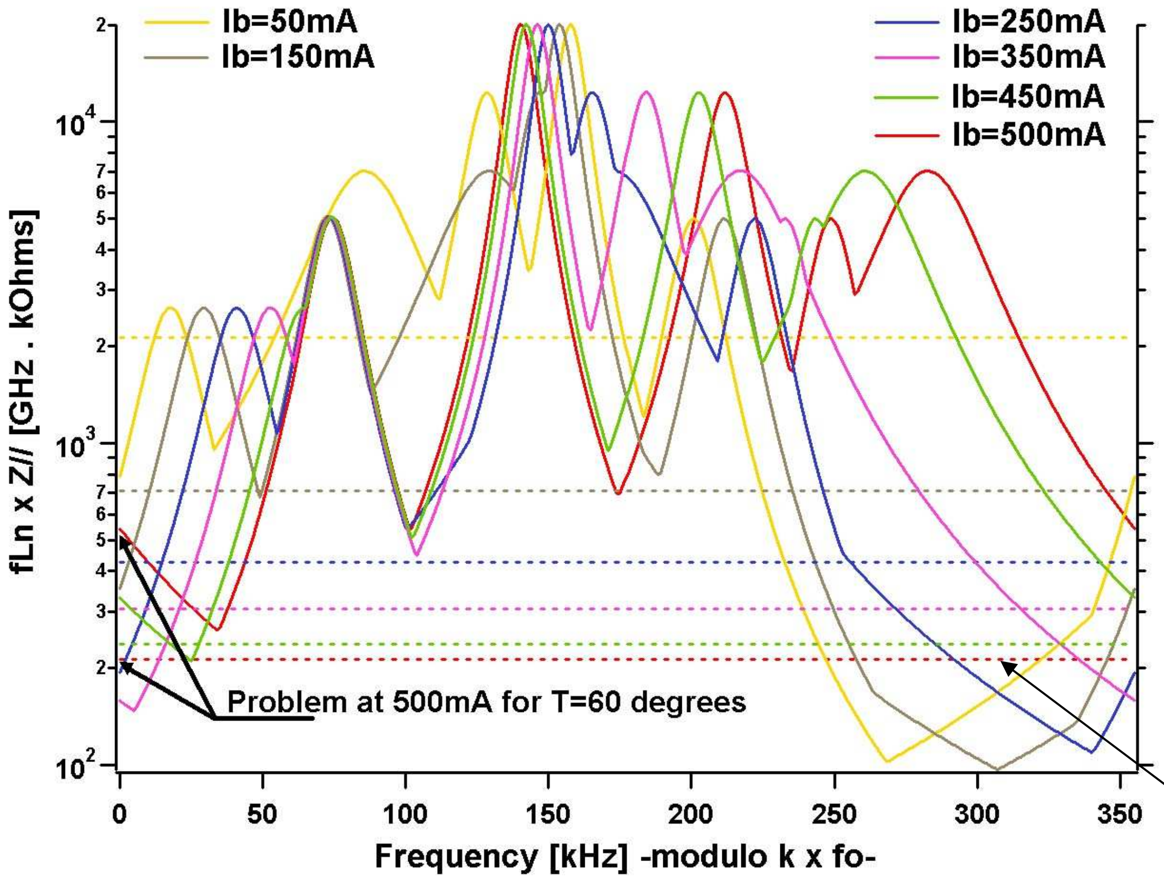
Such data generation tends to model the natural dispersion of the cavity parameters after manufacturing = to be as close as possible to the real case

12 IDENTICAL CAVITIES: stable points exist between
59.4 and 60.2 °C (margin of 0.8°C on cavity temperature variation)



Impedance threshold
for 12 cavites

18 IDENTICAL CAVITIES: NO stable point found to reach 500 mA with a single set of temperature

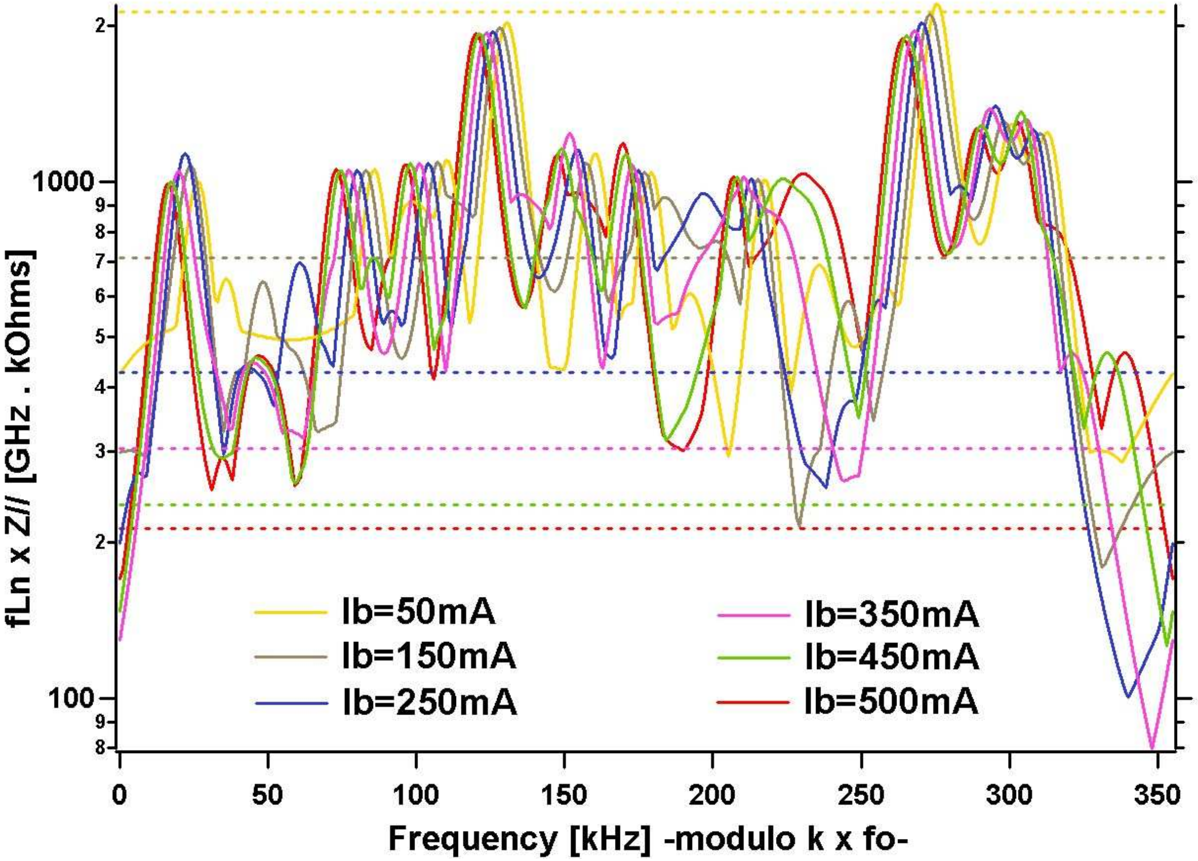


Problem at 500mA for T=60 degrees

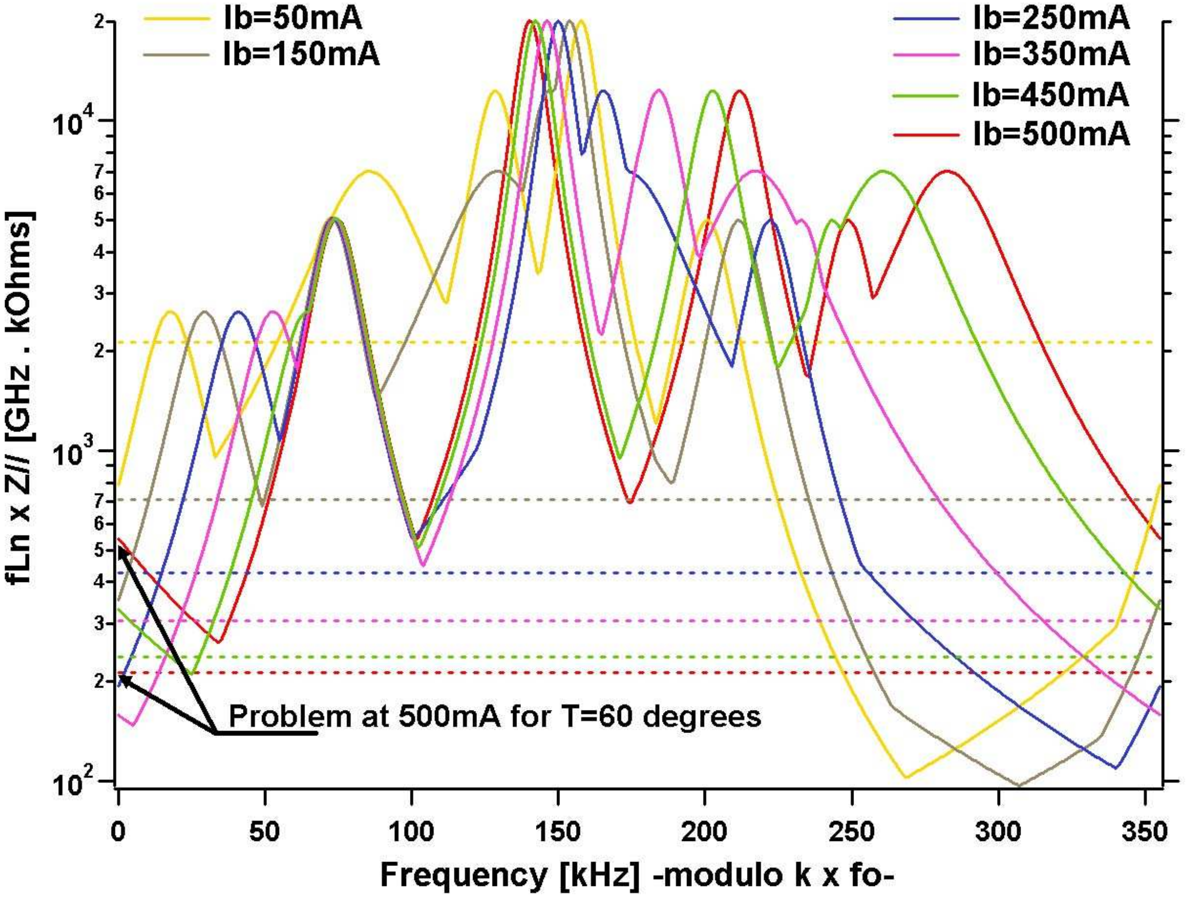
Impedance threshold
for 18 cavites

Plot for T = 60 °C

12 DIFFERENT CAVITIES: many stable points exist



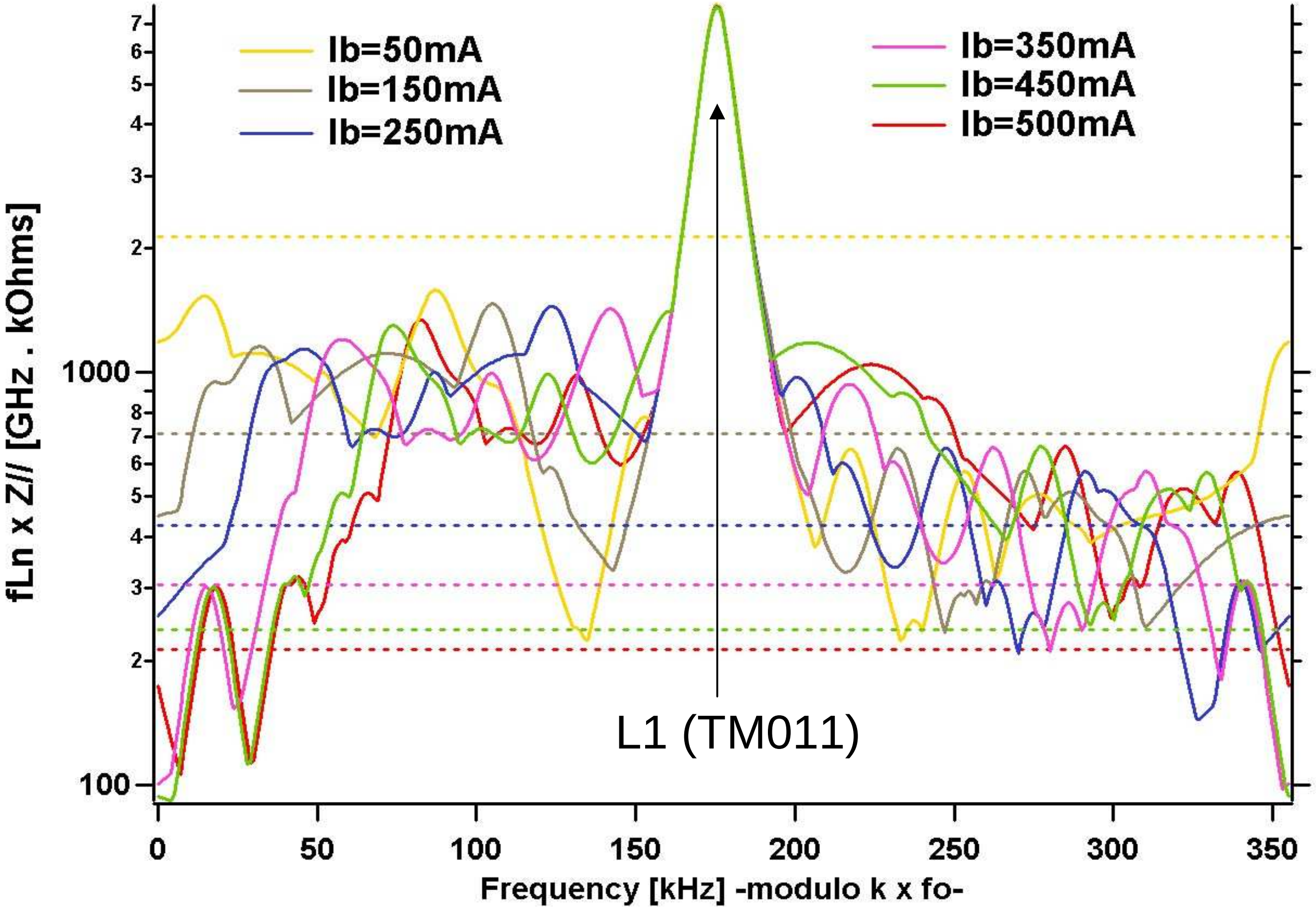
18 DIFFERENT CAVITIES



The maximum current which could be reach is

400 mA with one set of temperature

18 DIFFERENT CAVITIES AND THE TM011 FREQUENCY IS SYSTEMATICALLY PLACED IN THE MIDDLE OF THE WINDOW THANKS TO A SPECIFIC MECHANICAL PLUNGER



If the temperatures of the 18 cavities varies of 0.2 °C simultaneously, then instabilities may occur

ON CONCLUSION:

A STRONGLY DAMPED NC CAVITY WOULD BE THE MOST ADAPTED SOLUTION FOR THE ESRF TO REACH 0.5 AMPERE WITHOUT A COMPLEMENTARY LONGITUDINAL FEEDBACK SYSTEM.

THANK YOU !