Workshop on
Simulation of Power Dissipation and Heatload
from Wake Losses in Accelerator Structures

Heatload distribution in the ALBA stripline kickers on the basis of eigen mode simulations

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30th January

Outline:

- Introduction
- Addition of a connection bar to the horizontal stripline
- Addition of ceramical holders
- Comparison of wake field and eigen mode computation
- Heatload computation
- Power and temperature distribution (No coherent superposition of wake fields)
- Coherent superposition of the wake field (concept+formula)
- Coherent superposition of the wake fields applied on the striplines
- Power and temperature distribution (coherent superposition of wake fields)
- Stress distribution (coherent superposition of wake fields)
- Alleviation of temperature and stress with a copper connection bar
- Conclusions
- Homework

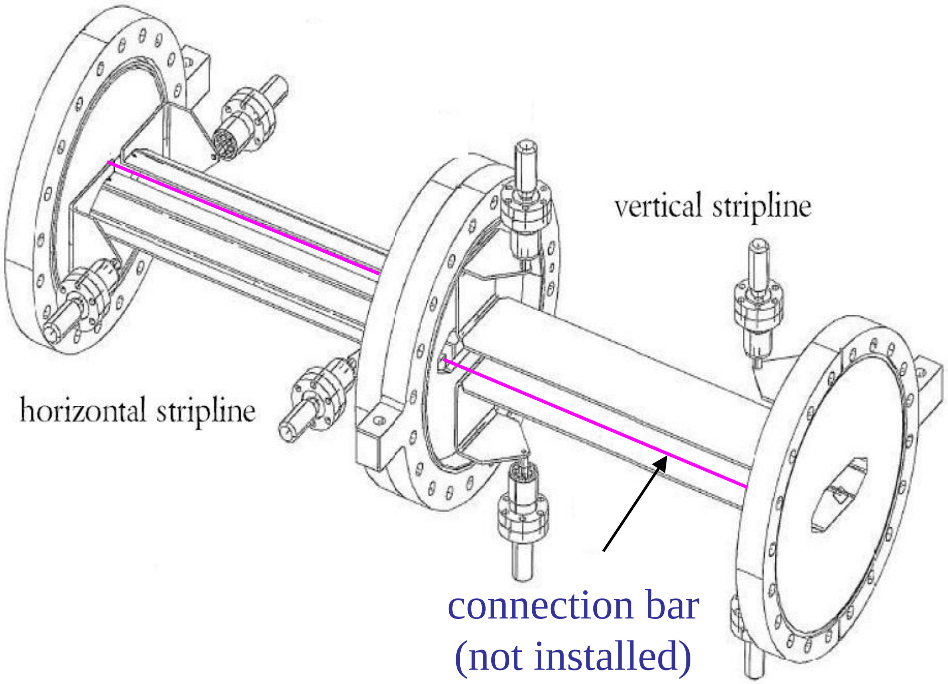
Introduction: ALBA Facility

- ✓ Synchrotron Light Source in Barcelona
- ✓ Up to 30 beamlines (7 on Day-1)
- ✓ Full energy Booster for Top-up injection
- ✓ 3 GeV Storage Ring, 268m circumference
- ✓ Emittance: 4.6nm*rad (4.3 design value)
- ✓ Maximum design current: 400mA

- ✓ SR Commissioning started 8 March 2011
- ✓ BeamLine Commissioning Autumn 2011

Horizontal and vertical stripline kicker

The design was originally adopted from the SLS



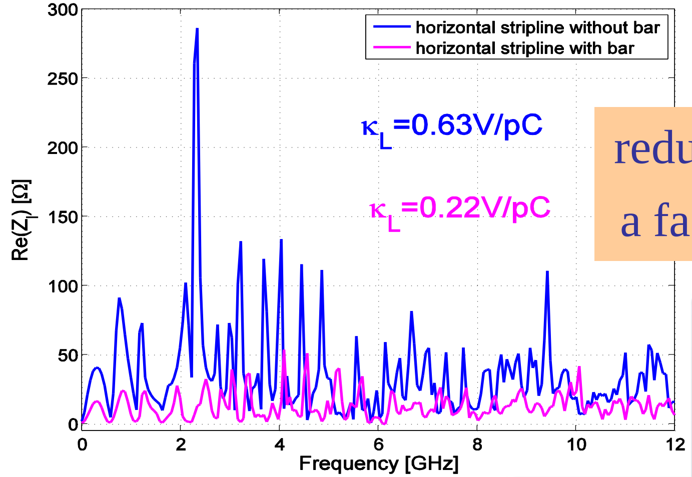
- An element of rather high impedance in all 3 planes

- For the better image current flow the effect of connections bars(in magenta) between the corresponding endplates were included in the simulation.

All loss factor computations are done with GdfidL applying the (natural) bunch length of 4.6mm

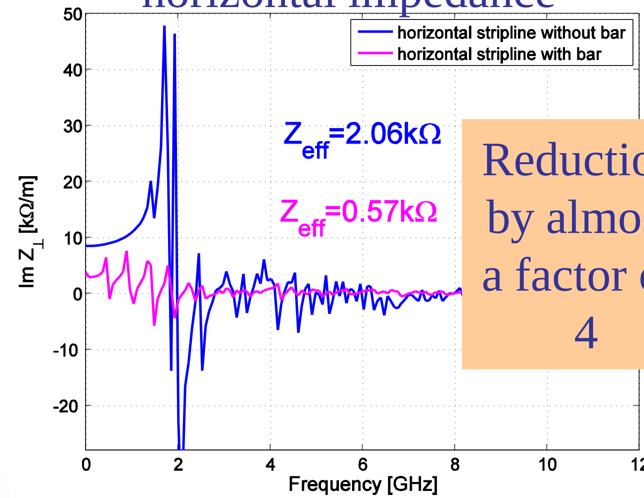
Effect of the connection bar on the Impedance of the horizontal stripline kicker

longitudinal Z_l (real part):



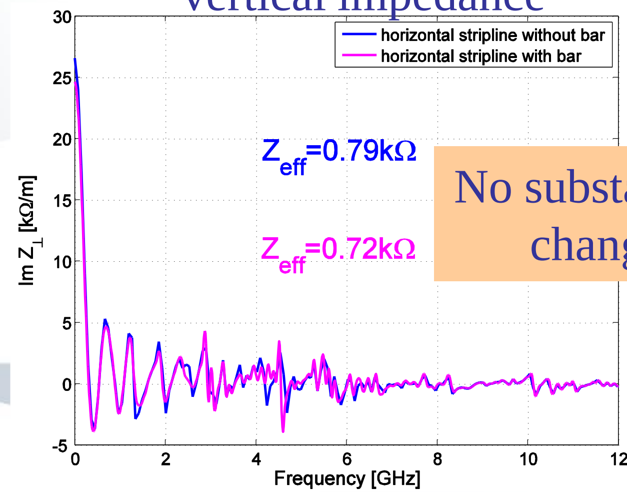
reduction by a factor of 3

horizontal impedance



Reduction by almost a factor of 4

vertical impedance

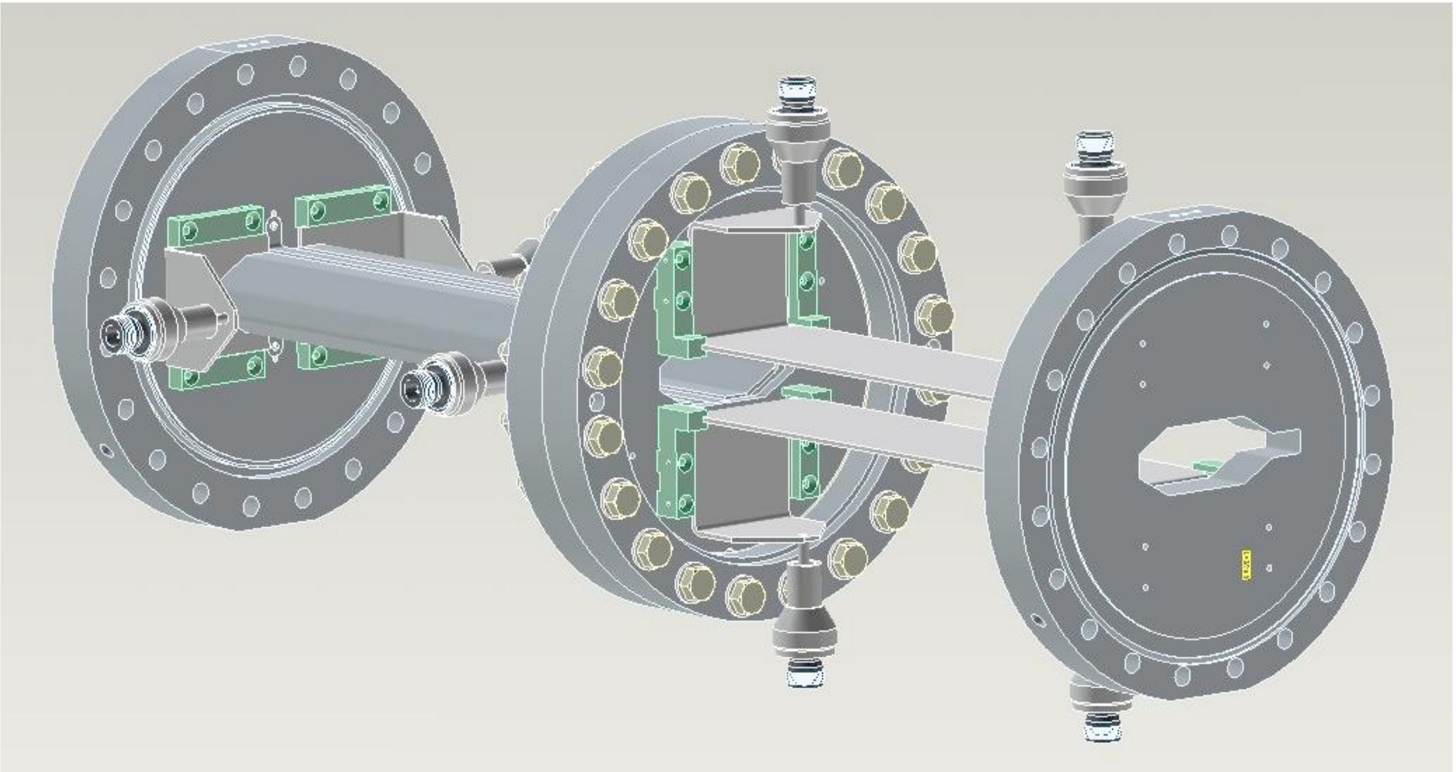


No substantial change

- The connection bar has almost no effect on the impedance of the vertical stripline (no comparison shown here)
- It has a significant effect on the impedance of the horizontal stripline
  → horizontal stripline will be built with connection bar

Addition of the ceramic holders

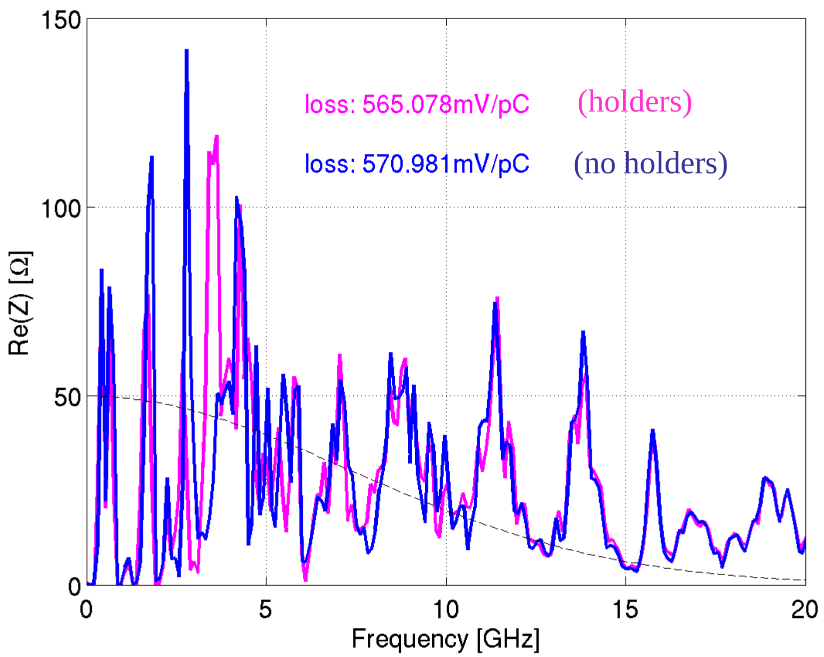
Another design change is the use of ceramic holders
in order to provide more mechanical stability to the electrodes



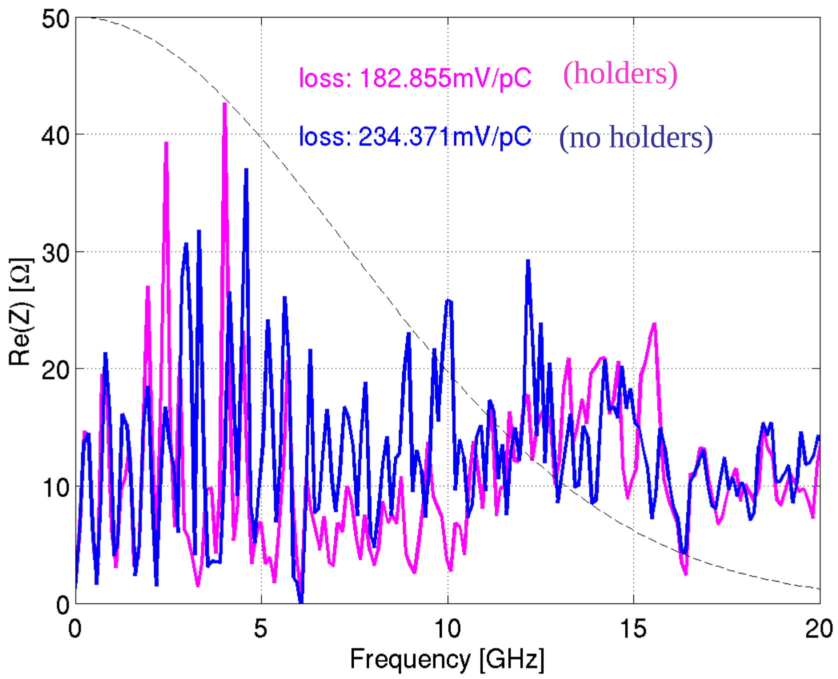
Ceramic MACOR© with ε=5.85

Wake field with ceramic holders

Vertical



Horizontal



The ceramic holders not only provide more mechanical stability but also reduce the losses in both striplines

The loss factor below the cut-off : 329mV/pC
Power@0.4A : 104W

TM cut-off 5.89 GHz

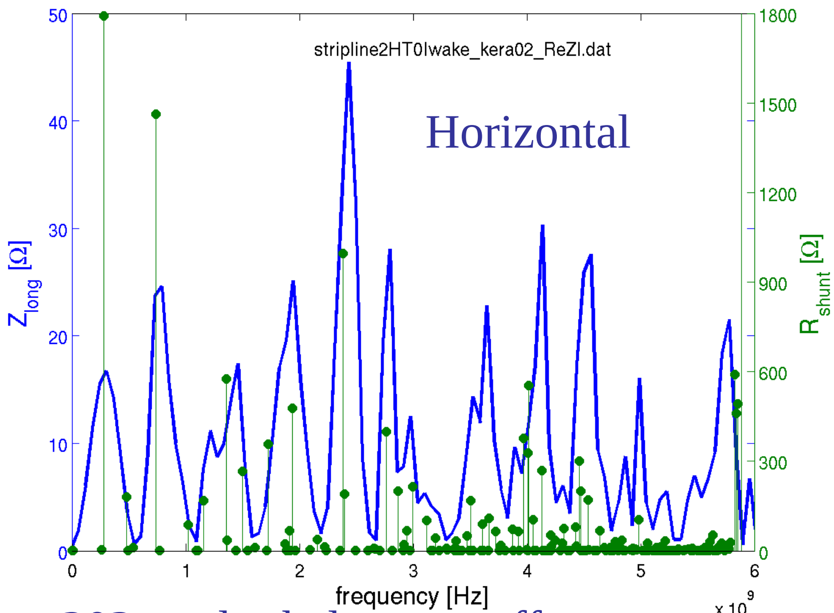
The loss factor below the cut-off : 116mV/pC
Power@0.4A: 37W

Despite these modifications the power load is still very high

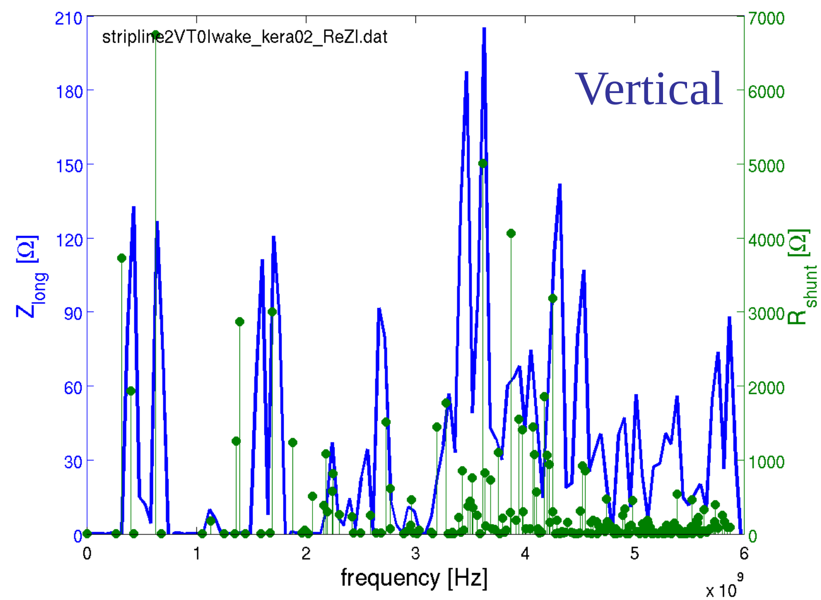
Wake field compared to Eigen mode computation

For the eigen mode computation dissipative losses were assumed.
stainless steel walls and lossy dielectrical material (tan(δ)=5.9e-3)

Each eigen mode is characterized by frequency, quality factor and shunt impedance.



203 modes below cut-off



202 modes below cut-off

Despite the difference between eigen mode and impedance spectrum
we assume that the loss factor in time- and frequency-domain is the same.

The loss factor is computed from quantities like resonance frequencies and R/Q which are universal

For the striplines the deviation between both loss factors(T/ω) is less than 10%.

Heat load distribution computation

For the power repartition the quality factors
of the different parts of the device are needed

$$\frac{1}{Q_L^n} = \left(\frac{1}{Q_{strip}^n} + \frac{1}{Q_{Tank}^n} + \frac{1}{Q_{ceramic}^n} \right) + \frac{1}{Q_{ext}^n}$$

Once the Q's known, the modal and partial loss factors can be computed:

$$\kappa_{partial} = \sum_{f_n < 5.9GHz} \frac{\omega_n}{2} \exp\left(-(\omega_n \sigma_\tau)^2 \right) \left(\frac{R}{Q} \right)_n \frac{Q_{Loaded\_n}}{Q_{partial\_n}}$$

sum over all modes

$$\kappa_{tot} = \sum_{partial} \kappa_{partial} = \kappa_{strip} + \kappa_{Tank} + \kappa_{ceramic} + \kappa_{ext}$$

$$P^n = \frac{I_{tot}^2}{f_{rep}} \kappa^n$$

Heat load distribution computation (how to get the Q-values)

The geometry is segmented in parts of different material.
The quality factor of a particular material segment is determined by switching on its resistivity whereas the other material segments are kept as PEC.

This is carried out for all material segments and for all modes.
Loss factors are computed for each mode and each segment.

$$\left.\begin{array}{l}\text{This is carried out for all material segments and for all modes.}\\ \text{Loss factors are computed for each mode and each segment.}\end{array}\right\} \rightarrow Q_{strip} \quad Q_{Tank} \quad Q_{ceramic}$$

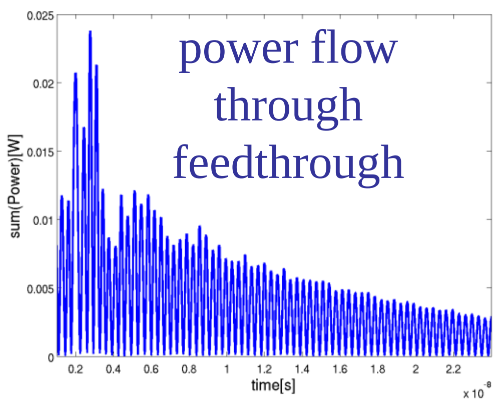
The determination of Q_{ext}:

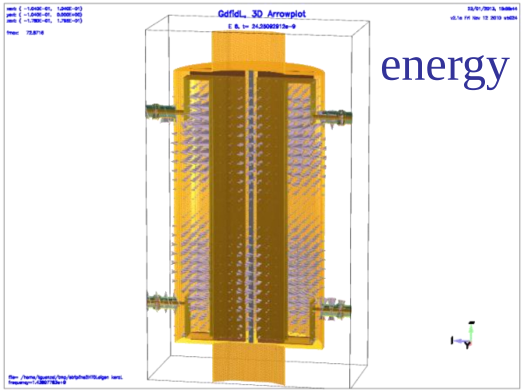
For each mode the power flowing through the feedthroughs is observed. The average power is normalized on the product of angular frequency and energy residing in the strip-line in order to get $1/Q_{ext}$. This method is not very precise though.

<u>Example:</u>

mode in hor. stripline

f=1.439GHz





Q_L=140

The beam pipe ports were assumed to have negligible power flow. (too simplistic)

Power distribution (NO coherent superposition of wake fields)

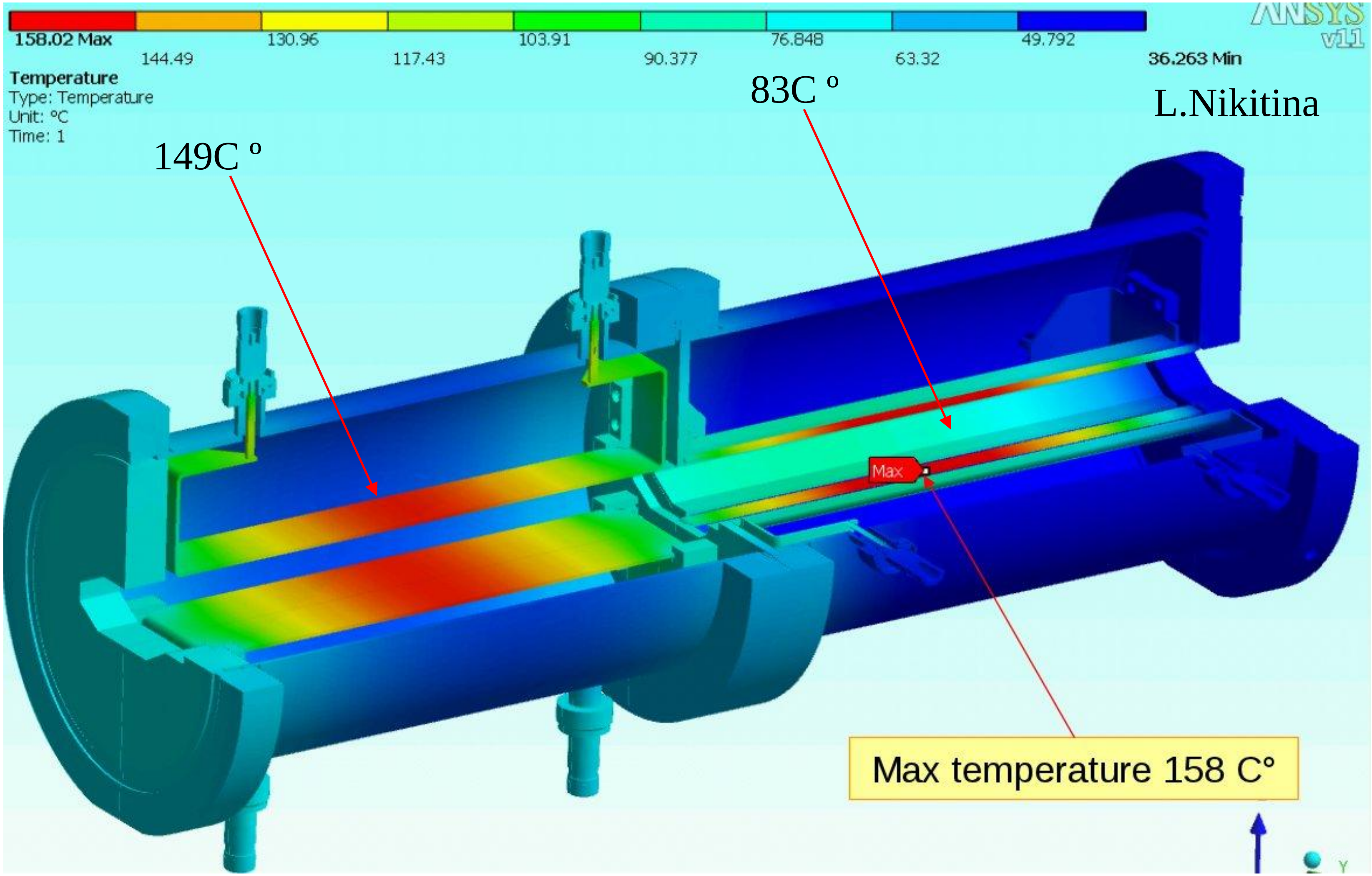
Homogeneous filling of 448 bunches making up 0.4A, separated each by 2ns

Assumption: Each bunch only sees its own wake field

	H	V
	Power[W]	Power[W]
wake field loss with connection bar	57.1	180.7
All below cut-off frequency	37.2	105.4
external load	21.6	61.4
inside device	15.6	44.0
electrode	3.4	12.9
all ceramics	7.3	18.1
connection bar/ feedthrough(FT)	1.5(bar)	2 (FT)
tank + endflanges	3.4	11

The ceramical holders catch most of the internal losses.

Temperature distribution in the both stripline kickers



only true under assumption of perfect contact,
otherwise the temperature is even much higher.

Homogeneous filling:

$$P_{loss} = \sum \mathrm{Re}(Z(p\omega_0))\,|\,\tilde{I}\,(p\omega_0)\,|^2$$

$$\kappa_l \rightarrow \kappa_l \cdot \frac{D}{D^2 \sin^2\left(\pi \frac{f_r}{f_{RF}}\right) + 1}$$ with $$D = Q_L \frac{2\, f_{RF}}{\pi\, f_r}$$ assuming D>>1

Consequence: The κ_L of a resonance (almost) coinciding with a harmonic of f_{RF} is enhanced by D

$$\kappa_l \rightarrow \kappa_l \cdot D$$ resonance like a narrow-band resonator

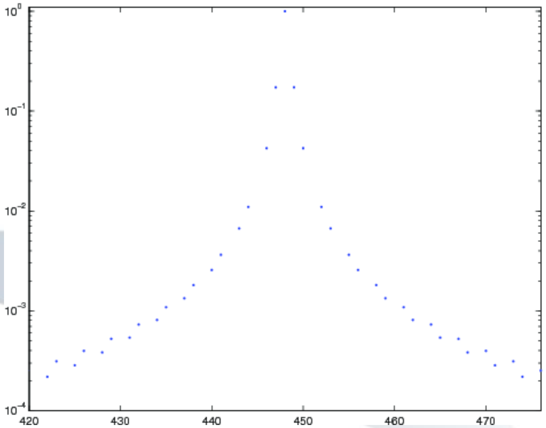
On the contrary the κ_L of a resonance at $f_r \approx f_{RF}/2$ is suppressed by 1/D (assuming D>>1)

$$\kappa_l \rightarrow \kappa_l \cdot \frac{1}{D}$$ resonance like a narrow-band resonator

Non-homogeneous filling, e.g. 2/3-filling:

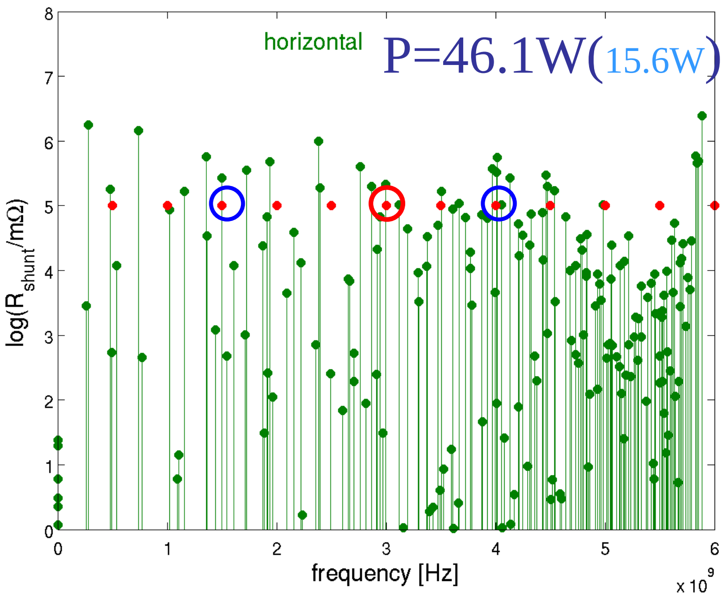
Already coincidence of a resonance with satellite line can produce power enhancement.

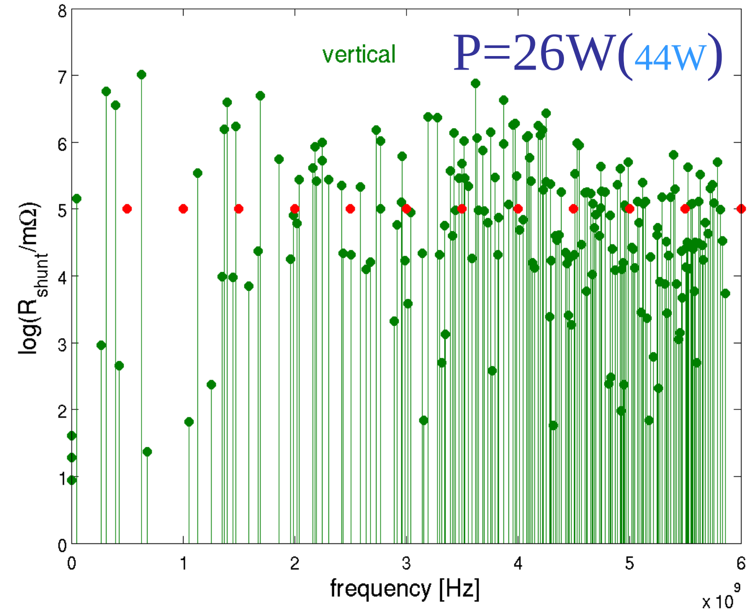
Fortunately the strength of the lines decays very quickly.



Coherent superposition of the wake fields applied on the striplines

Homogeneous filling:





the coincidence is rather strong
at 1.5, 3 and 4GHz
make up ~90% of heatload

@3GHz: $\Delta f = f_r - f_{RF} = 84\,\mathrm{keV}$

the coincidence is rather weak.

To get a strong effect the resonance has
to be very close to the bunch repetition frequency.

$Q_L=1766$, $R_s=163$, $\exp(-(\omega_r\sigma_\tau)^2)=0.92$, $D=187.4$ $\kappa_L=.8\mathrm{mV/pC} \longrightarrow \kappa_L=150\mathrm{mV/pC}$!!

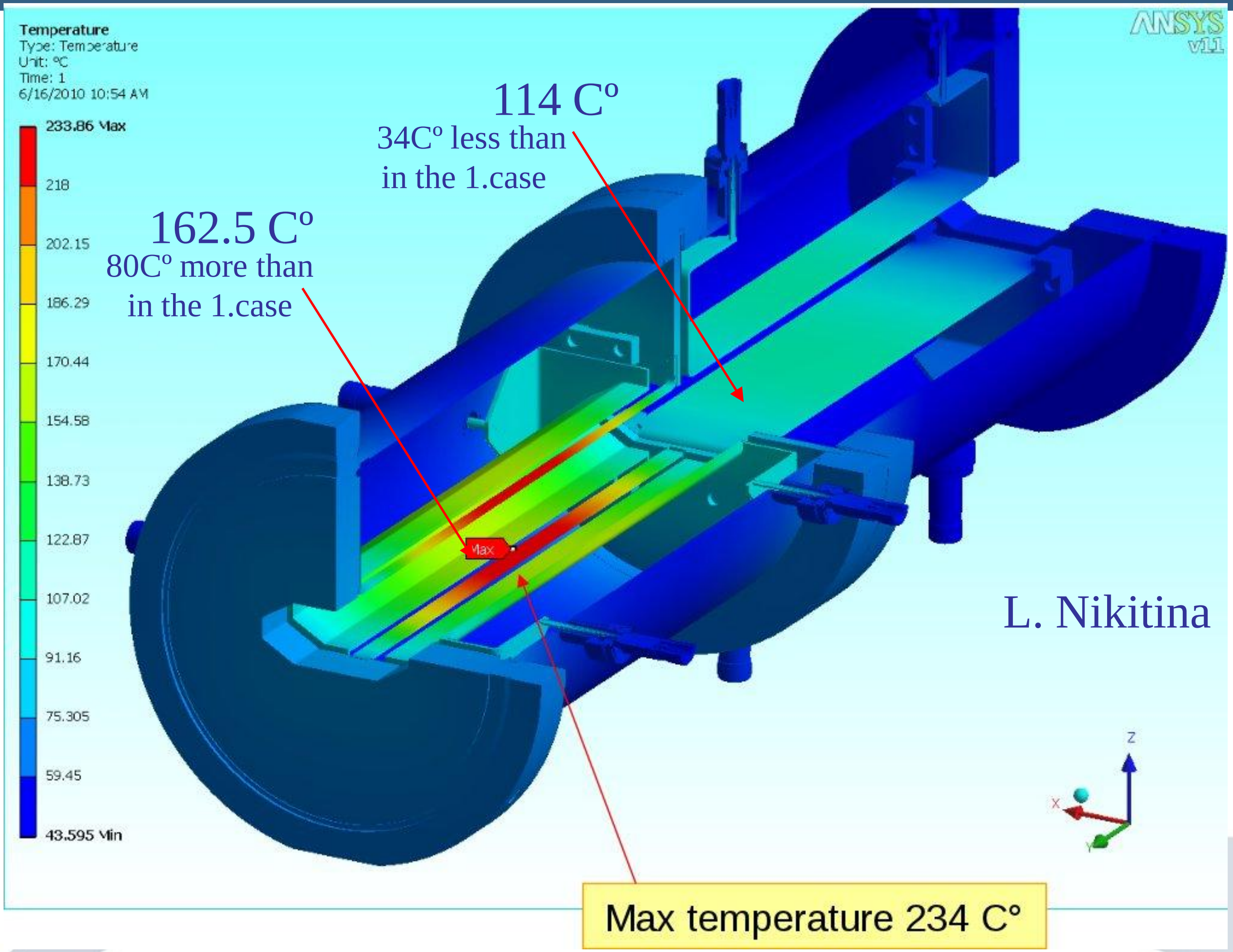
This coincidence makes up 78% of the total heatload of the hor. stripline
The 2 other coincidences make up another 12.3% of the total heatload
} 90%

Power repartition(coherent superposition of wake fields)

	H	V
	Power[W]	Power[W]
All below cut-off frequency	85.9	47.7
external load	39.8	21.7
inside device	46.1	26.0
electrode	12.8	7.3
all ceramics	14.6	11.5
connection bar	2.3	
feedthrough	0.7	0.8
tank + endflanges	15.7	6.4

Again the ceramical holders catch large part of the internal losses.

New temperature distribution (coherent superposition of wake fields)

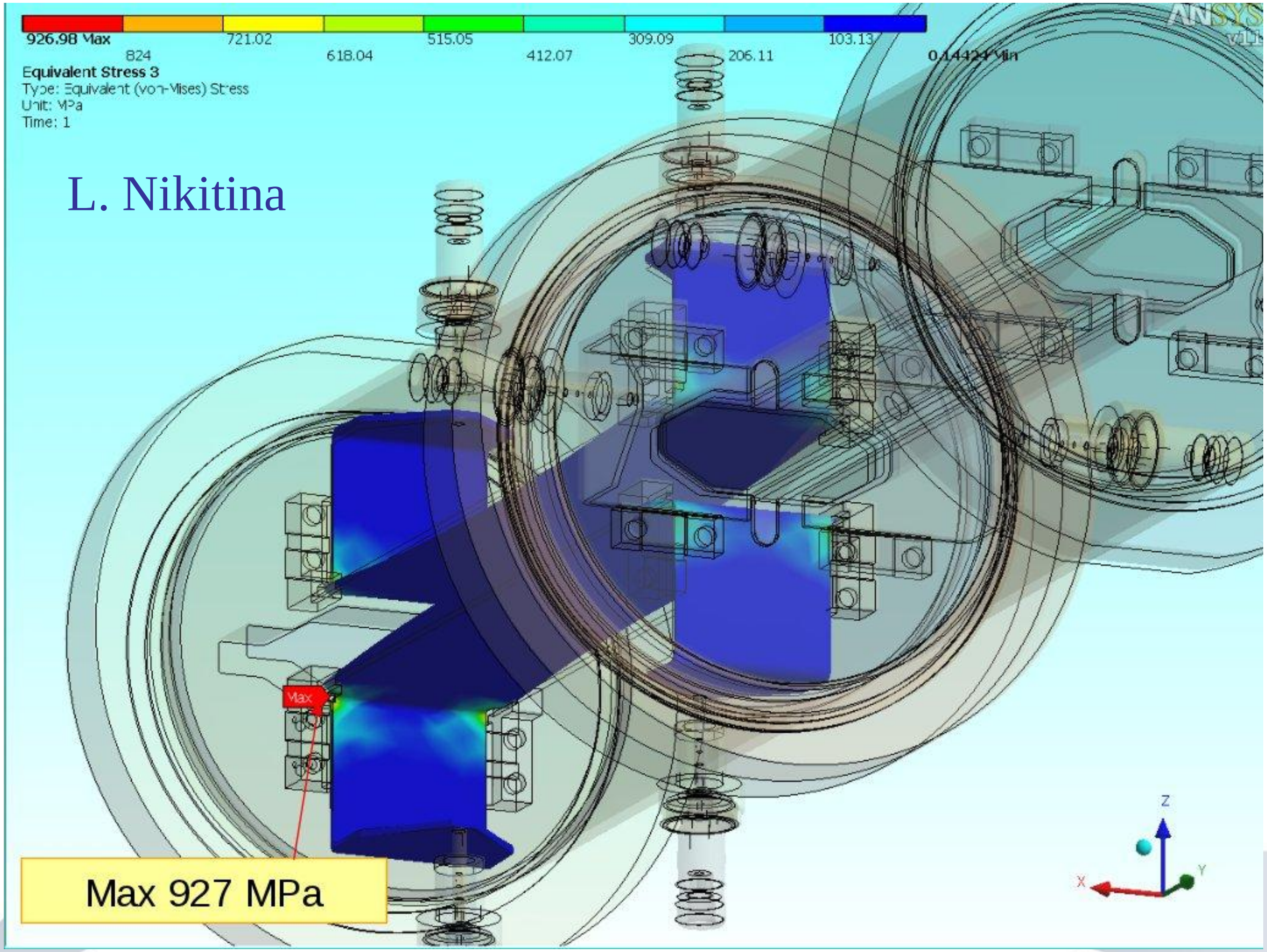


Large temperature also means large distortion

The stress of the electrode held at the ceramic holders is tremendous

However, if the ceramic holders are removed the temperature reaches even higher values

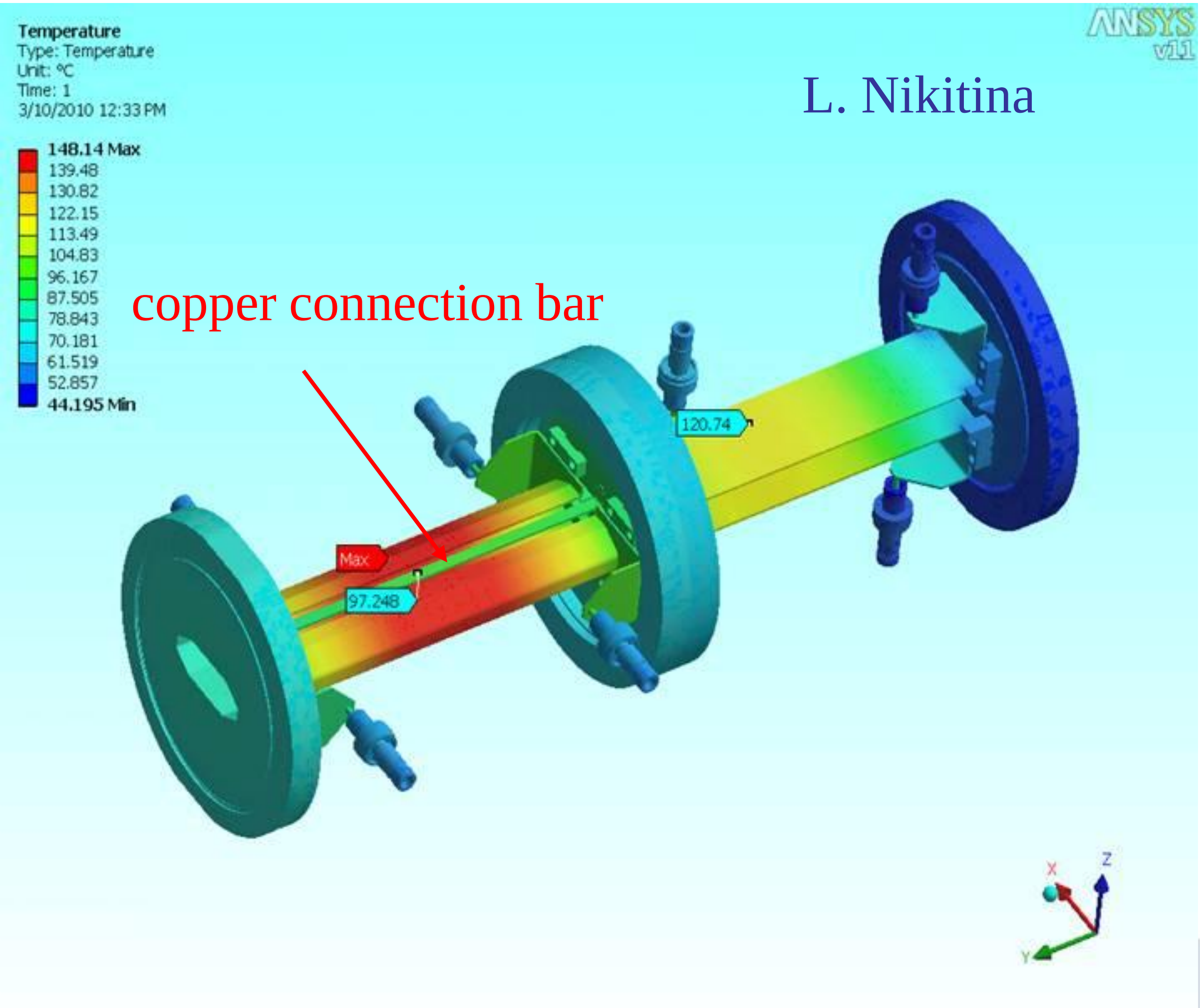
Corresponding stress distribution



Electrode under stress inside the ceramic holders

Connection bar under similar stress at its ends touching the flanges

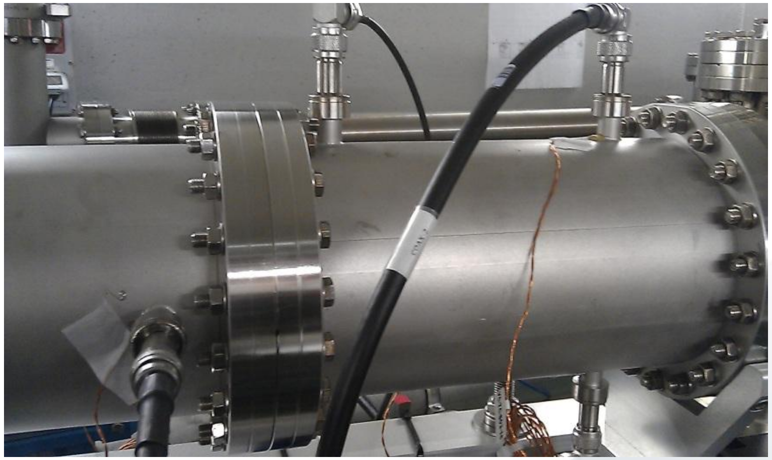
Temperature distribution with a copper bar



The use of a copper bar substantially would reduce the bar's temperature to less than 100C°

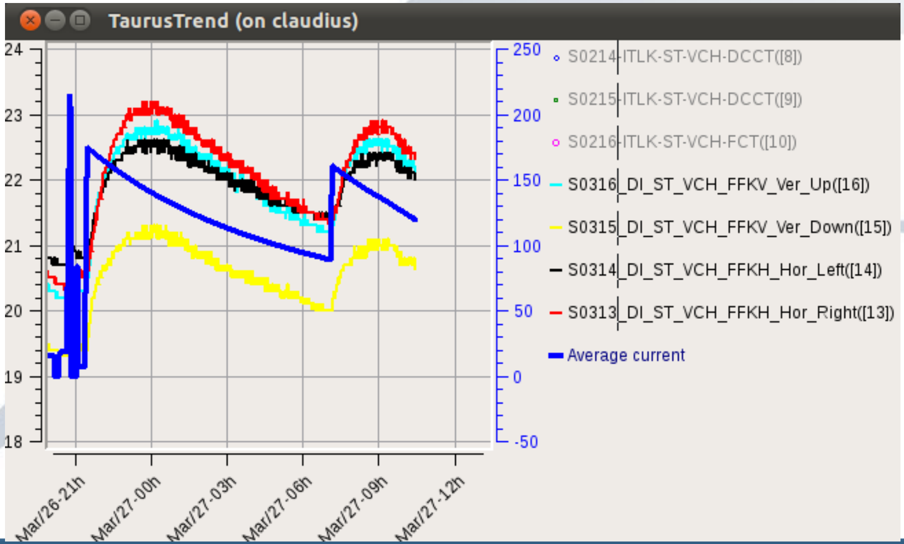
But actually this proposal was never realized.

FFK Installed at S3



Thermocouples at feedthroughs

Evolution of Temperature during 150mA fill (Decay-mode):



Ta Increase: 2ºC
Max Ta: 23ºC

Conclusions

Incoherent power distribution (a bunch does not suffer the wake of the precedent bunches)

44W vertical, 15.6W horizontal

Coherent power distribution (a bunch suffers the wake of the precedent bunches):

26W vertical, 46W horizontal

It was proposed to use a copper bar instead of SS-bar to mitigate temperature and stress, but the proposal was not realized.

No sensible temperature increase ($I \leq 150$mA) noticed yet.

Several questions remain open:

- Which power distribution (non-coherent or coherent wake) has to be taken ?
- Is the heat load really that high ?
- If yes how to cope with the heat load ?

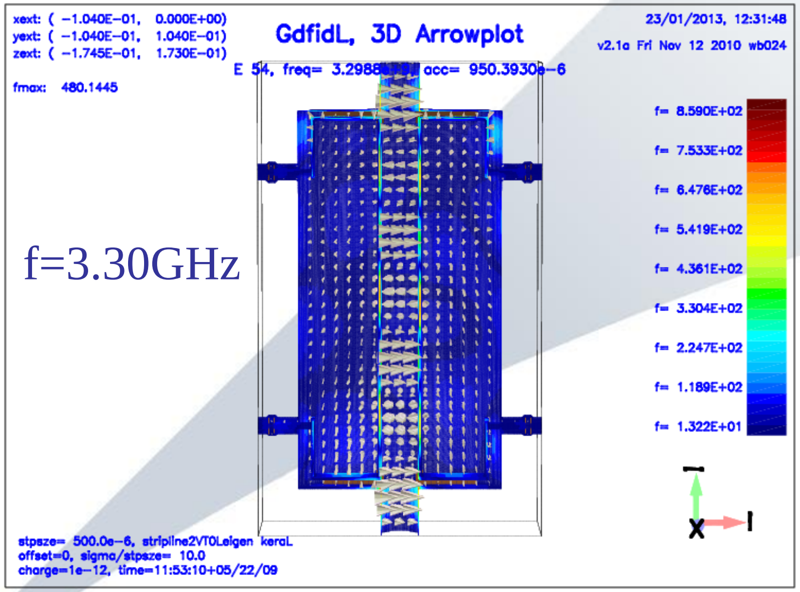
It is probable that some aspect of the analysis had not be considered correctly.

Conclusions

- Q_{ext} = [energy·ω]/[Powerflow in T-domain] is not precise enough.

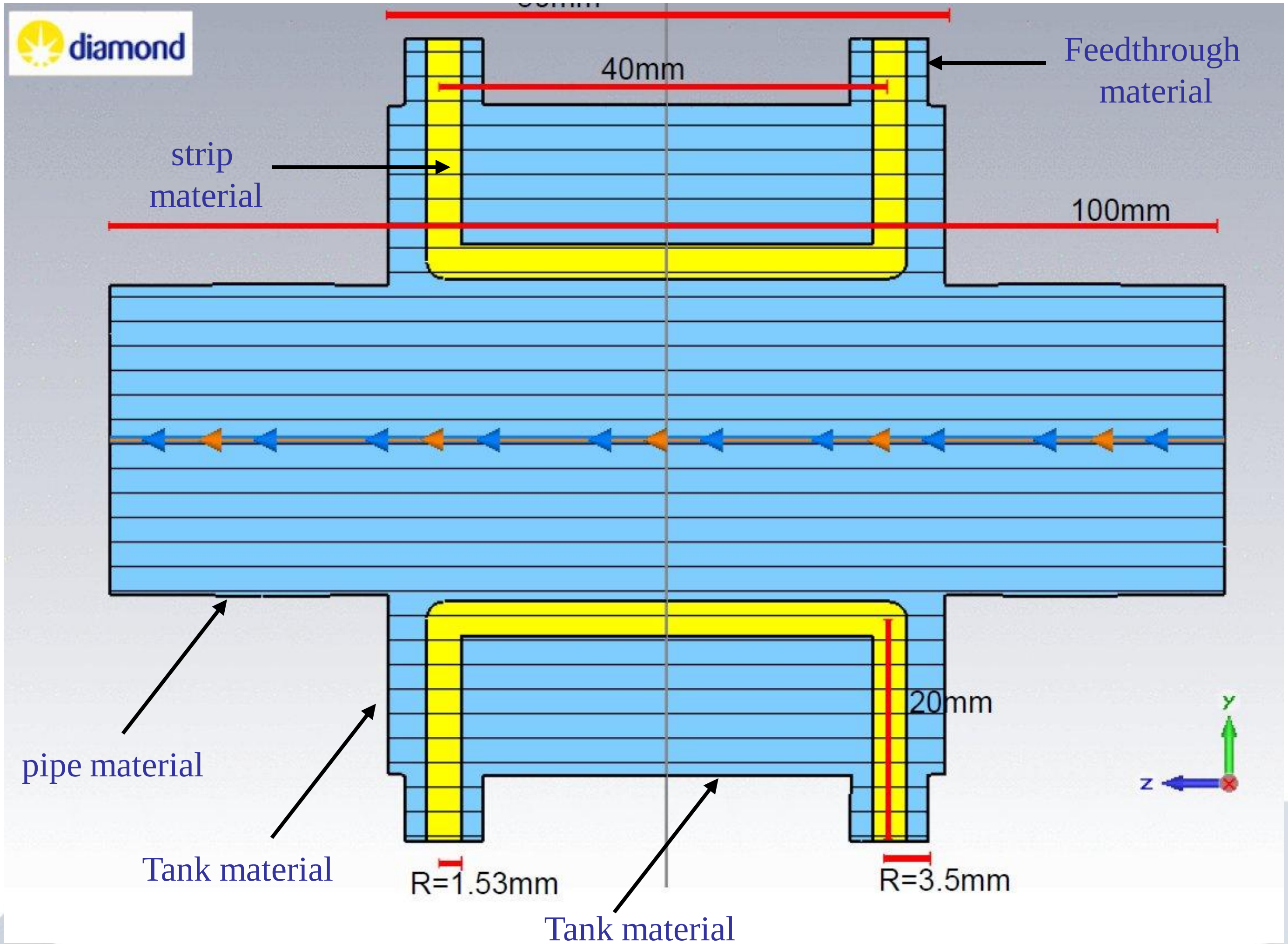
When the Q_{ext} s were computed (2009), eigen mode computation with absorbing boundary conditions was still not implemented in GdfidL.

- Modes above the first (propagating) TE-mode (2.38GHz): can they escape from the stripline kicker



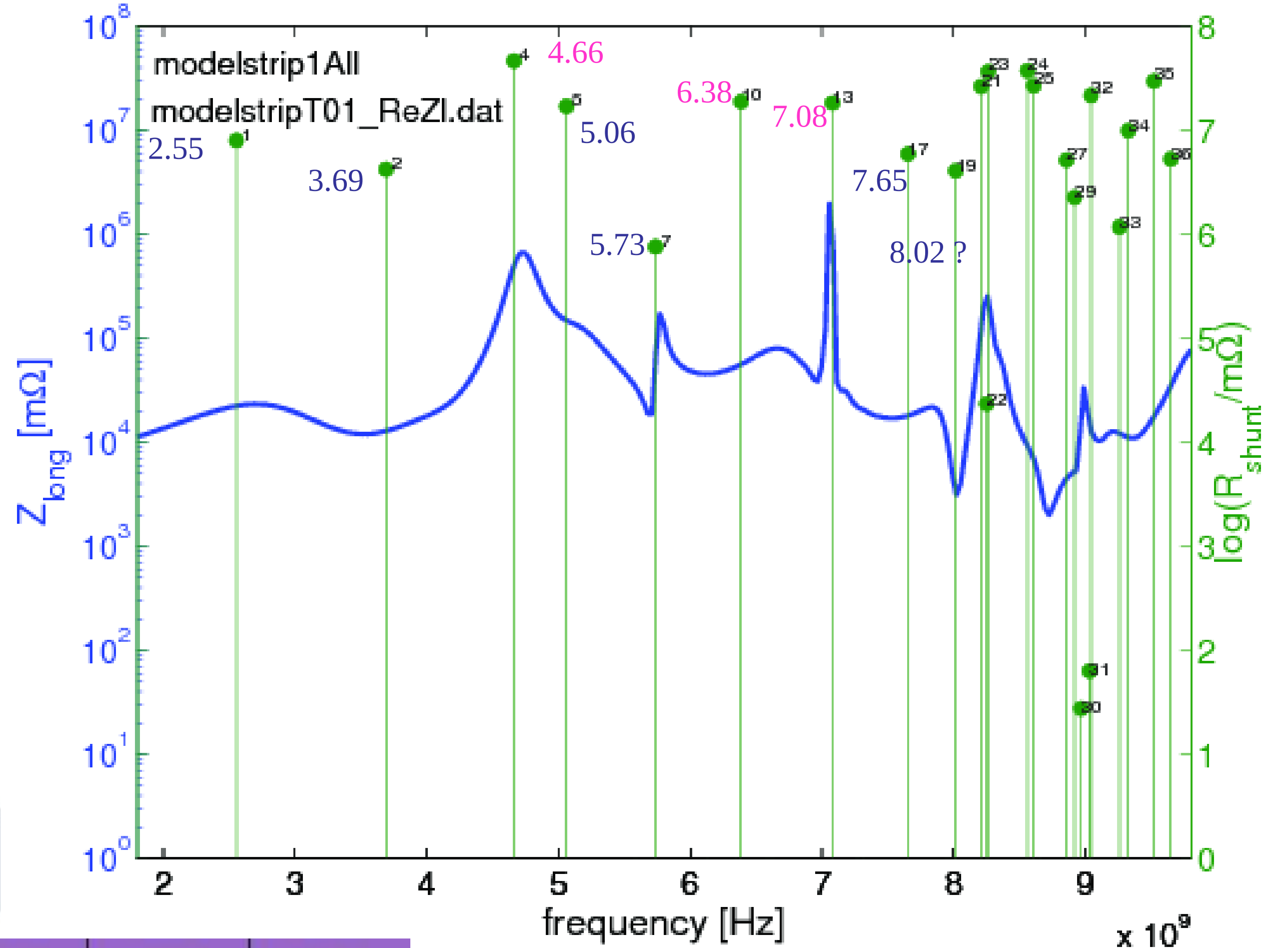
Proposal of Guenther: use absorbing boundary conditions

homework



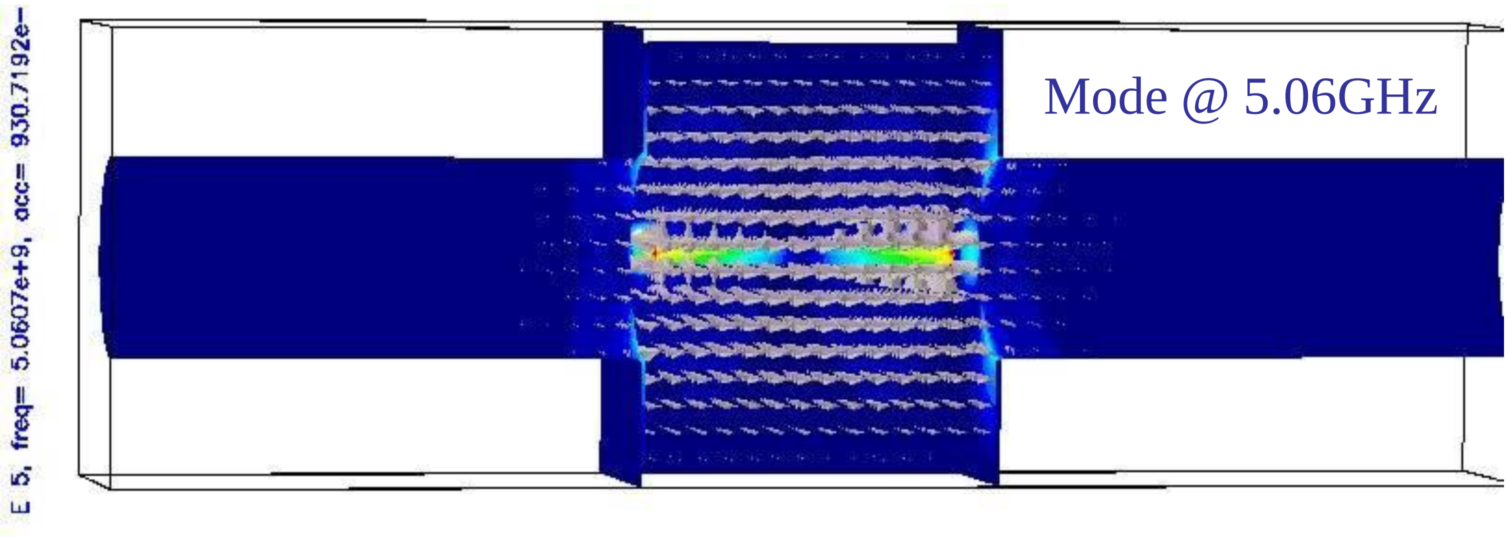
f_{TM}=8.18GHz, f_{TE}=6.27GHz modes computed up to the TM cut-off

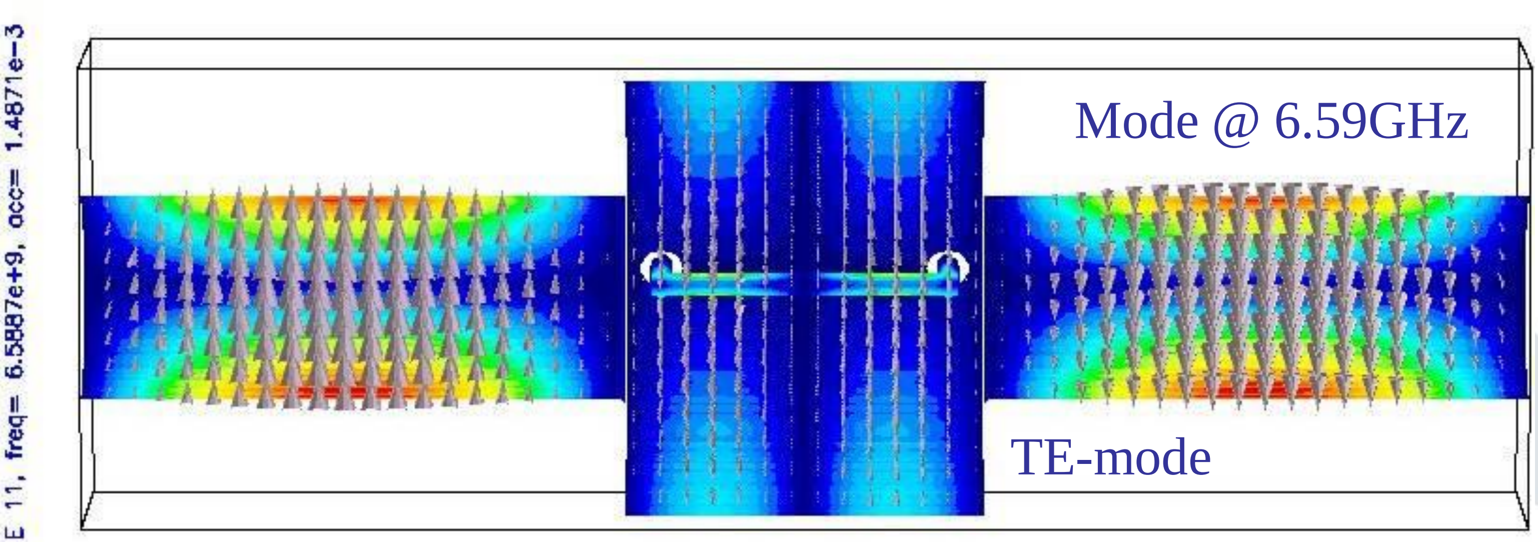
homework



fres[GHz]	Qdis	Qext	Qload
4.66	1754.9	16.88	16.71
6.38	2221.2	113.07	107.6
7.08	2907.9	1428.2	957.8

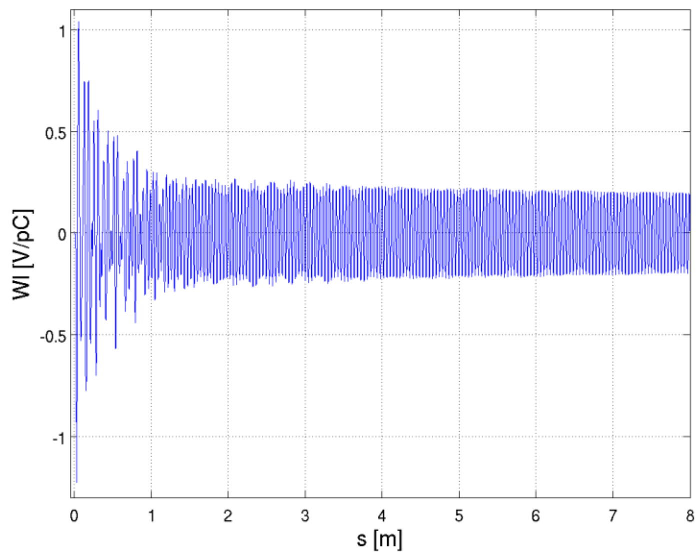
homework

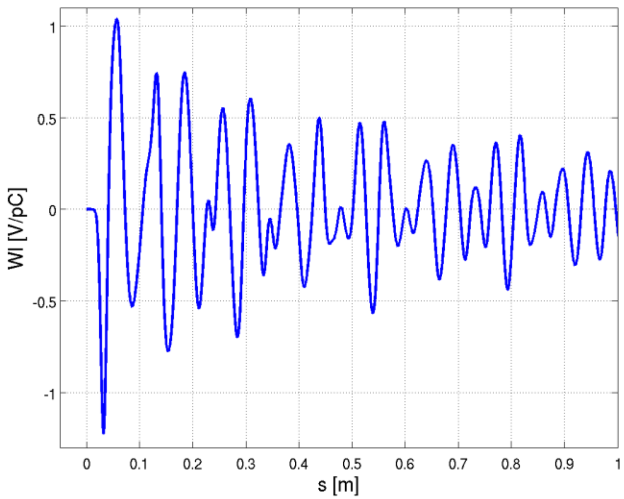




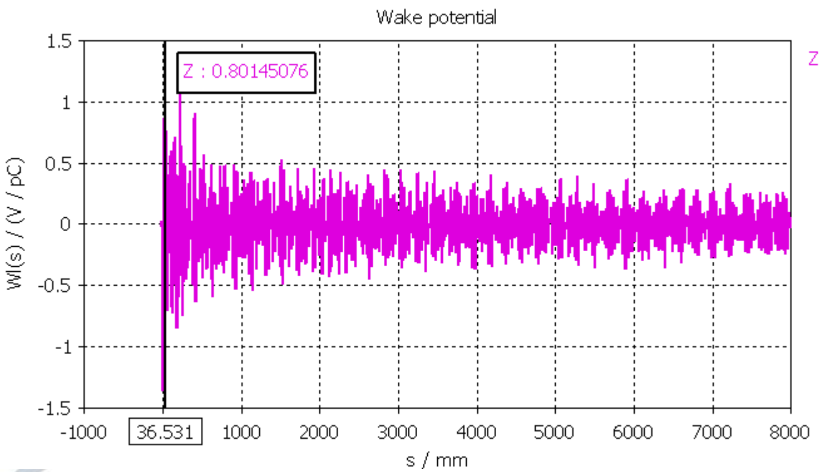
it does not contribute to the dissipative loss factor R_s=1e-12Ω~0

homework



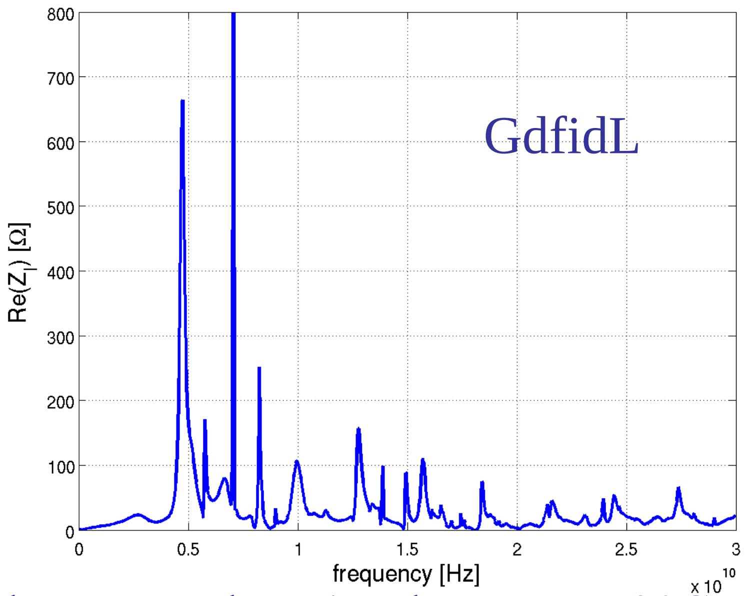


Longitudinal wake field (gaussian excitation of 5mm length)

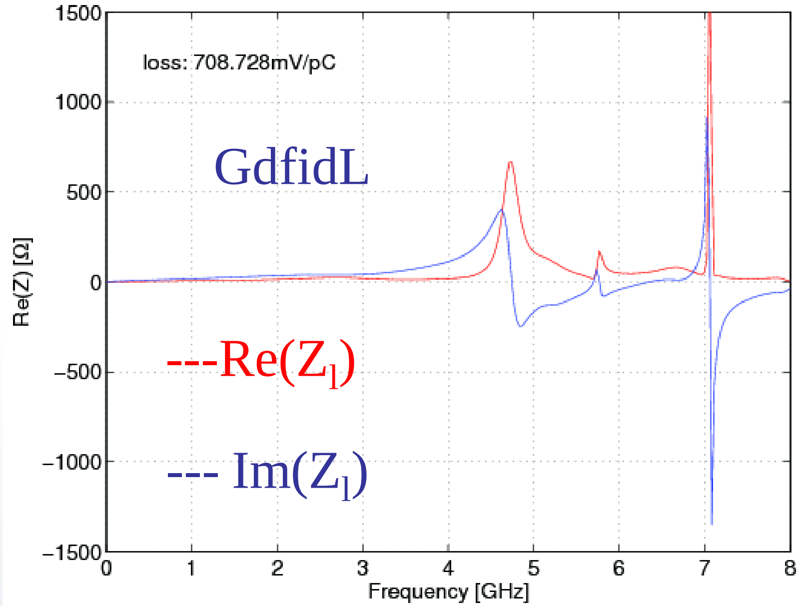


CST computation B.Bravo

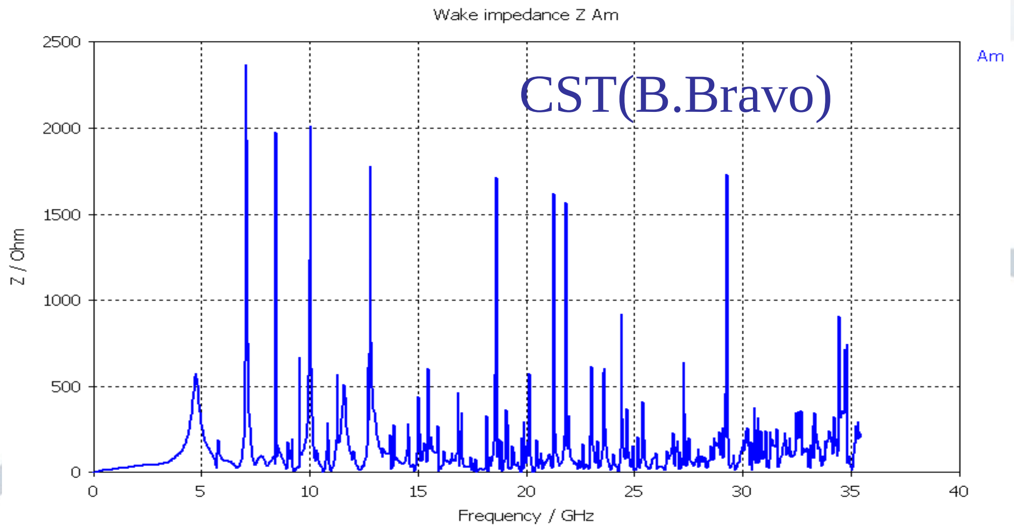
homework



long. Impedance' real part up to 30GHz



Long. Impedance up to the cut-off frequency of ~8GHz



homework

	tank	feedthrough wall	strip	coaxial loss	pipe(dis.+rad.)	total
loss factor[V/pC]	0.033	0.006	0.004	0.649	0.001	0.694
energy[J]	3.30E-008	5.86E-009	4.20E-009	6.49E-007	1.09E-009	6.94E-007
Power[W](ALBA)	10.66	1.876	1.345	207.7	0.349	221.96

ALBA conditions: bunch repetition frequency 0.5GHz, 448 bunches, 0.4A.