# EuroTeV High Bandwidth Wall Current Monitor

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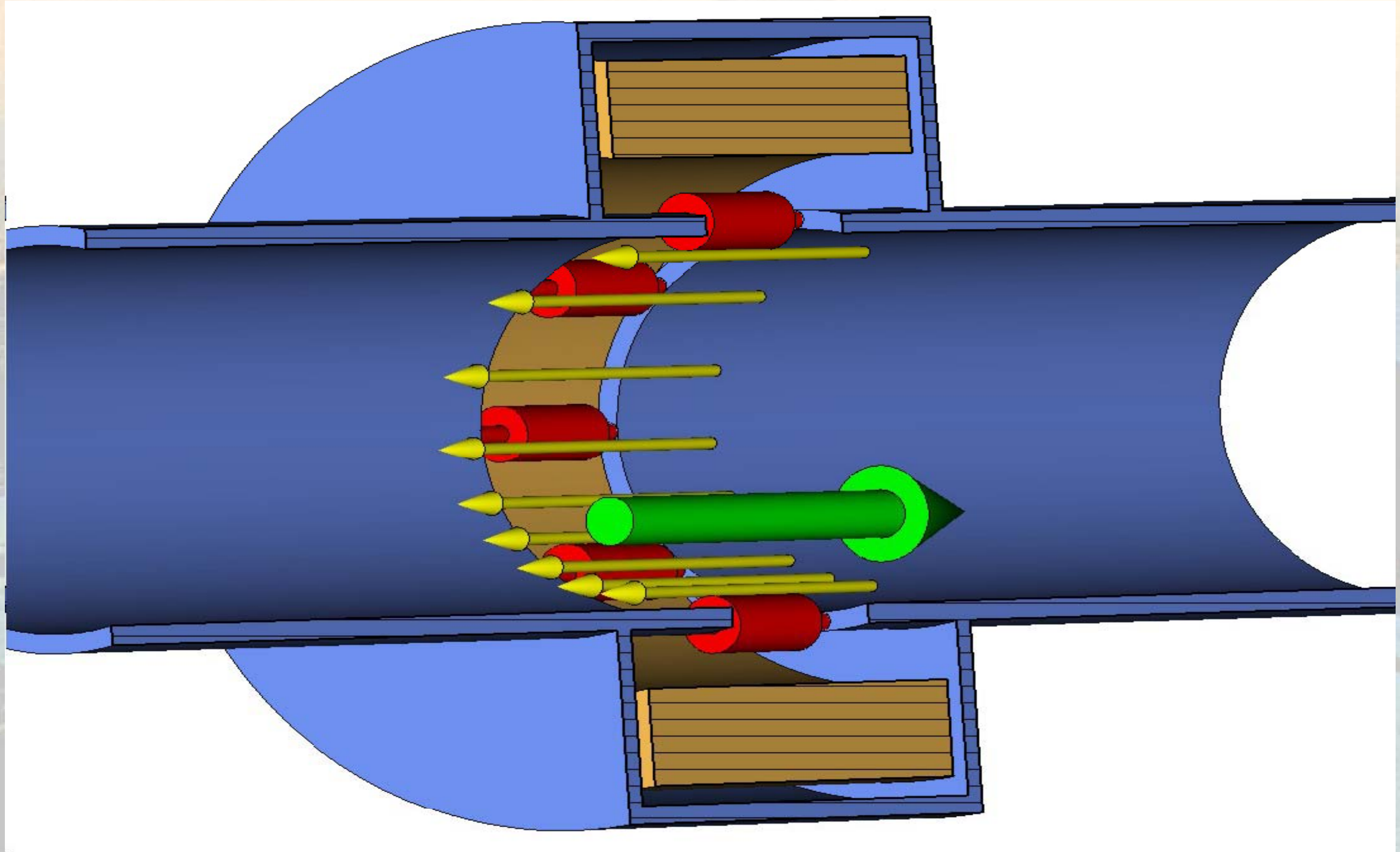
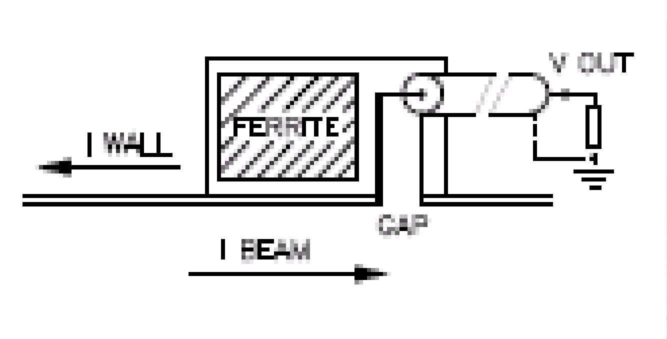
# Wall Current Monitors

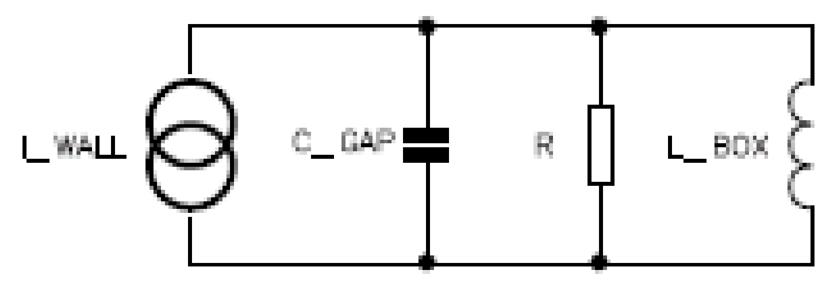
Wall Current Monitors (WCM) are commonly used to observe the time profile and spectra of a particle beam by detecting its image current.



# A first approach using a simple circuit model

The presence of the ferrite is fundamental in order to decrease the low frequency cut-off of the structure



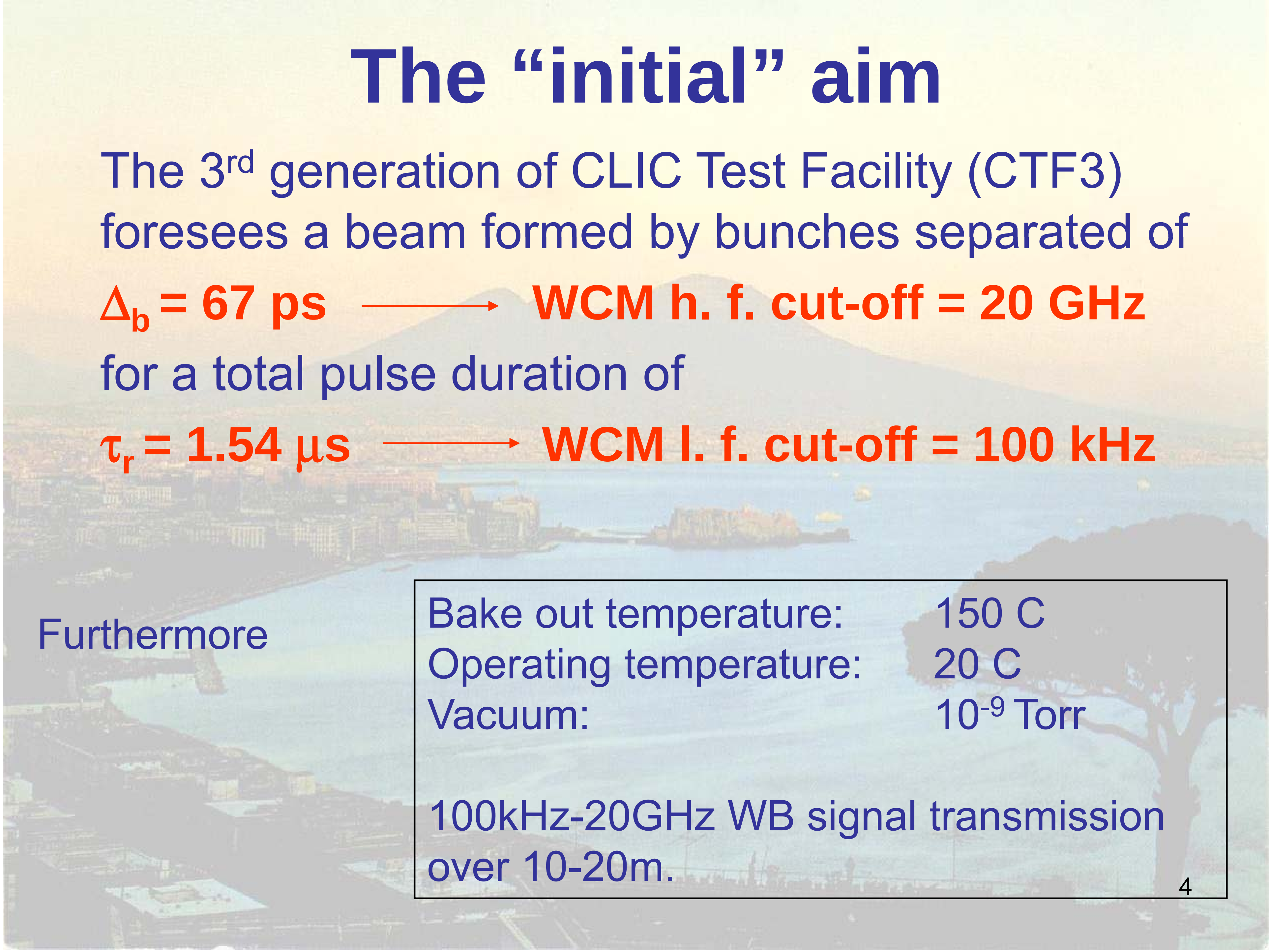


In the circuit representation is
- R the measuring resistance
- L_BOX the inductance of the box seen at gap
- C_GAP the capacitance across gap

$$F_{low\,cut-off} = \frac{1}{2\pi}\frac{R}{L}$$

$$F_{high\ cut-off} = \frac{1}{2\pi}\frac{1}{RC}$$

Note: When the distance between the WCM elements becomes comparable to the free space wavelength of the propagating fields, the circuit modeling is not reliable and a study of the 3D structure has to be performed by using e-m CAD!



# The “initial” aim

The 3rd generation of CLIC Test Facility (CTF3) foresees a beam formed by bunches separated of

**$\Delta_b$ = 67 ps $\longrightarrow$ WCM h. f. cut-off = 20 GHz**

for a total pulse duration of

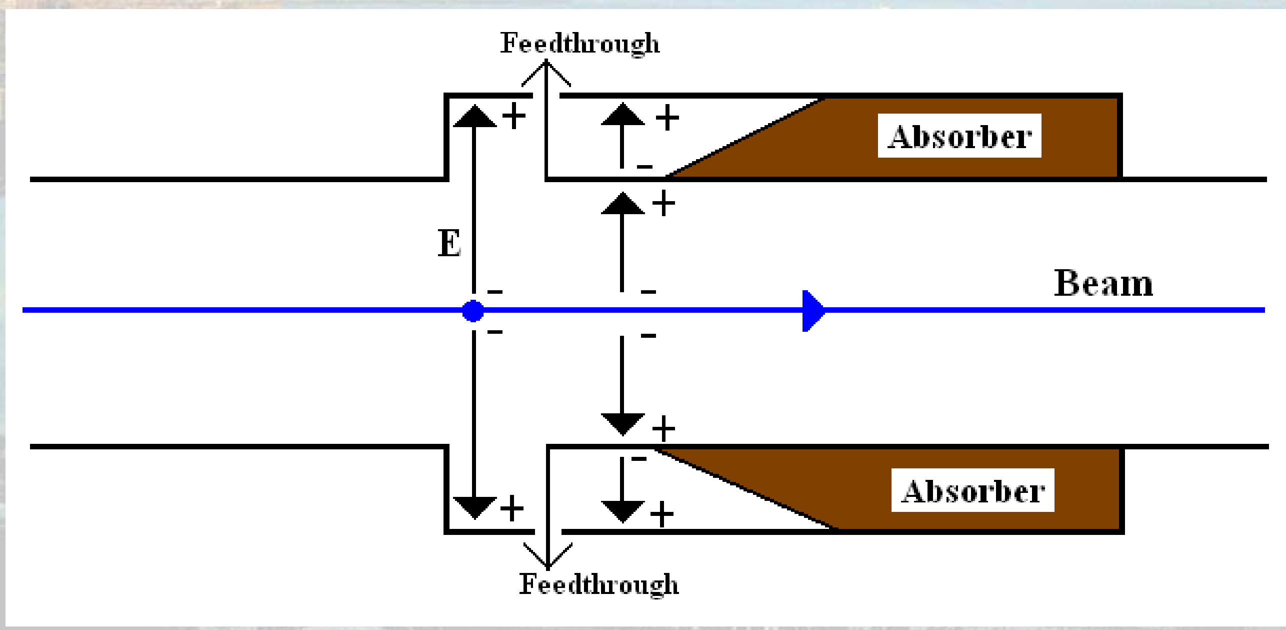
**$\tau_r$ = 1.54 $\mu$s $\longrightarrow$ WCM l. f. cut-off = 100 kHz**

Furthermore

| | |
|---|---|
| Bake out temperature: | 150 C |
| Operating temperature: | 20 C |
| Vacuum: | $10^{-9}$ Torr |

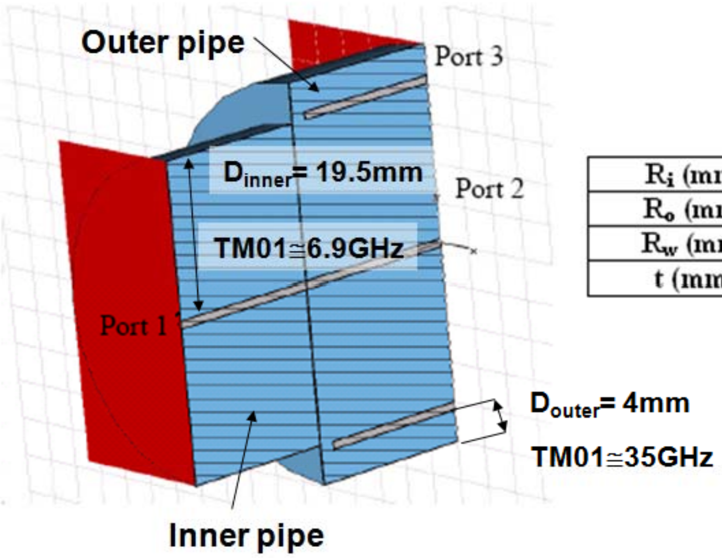
100kHz-20GHz WB signal transmission over 10-20m.

Since we needs ≅ 20GHz of bandwidth, the working principle of our structure is shown below: the electromagnetic field dragged by the bunches passes in a small longitudinal gap made on the wall pipe and it is ”shaved”. A part of this portion of the electromagnetic field is captured by a coaxial antenna in the first section of a bigger coaxial line, while the rest is damped along the line.

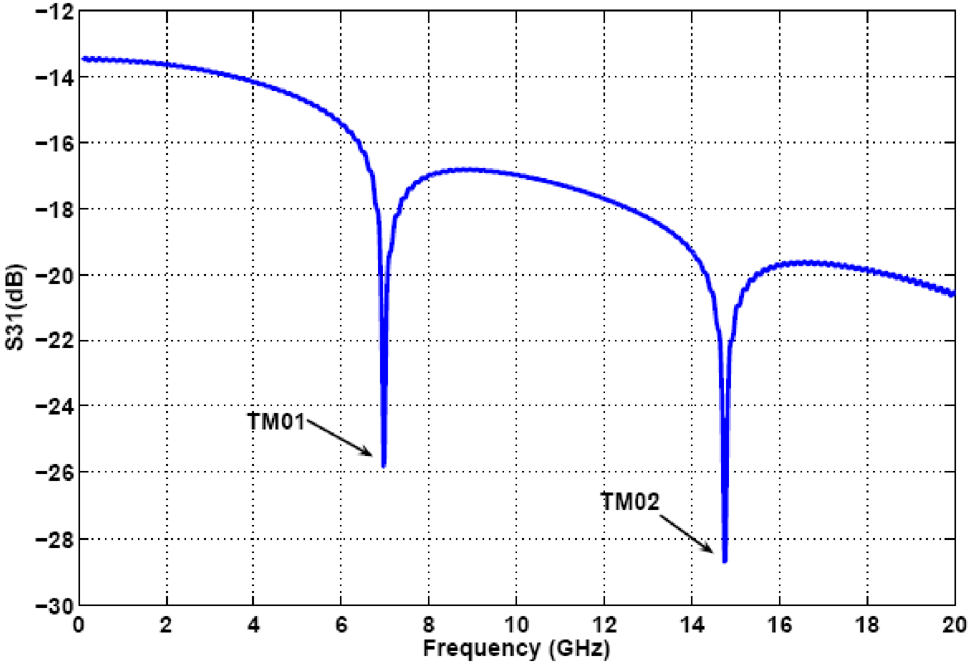


# The gap resonances

The different cross sections between internal and external pipe does not allow all the possible field configurations to propagate from the inner to the outer pipe. This will produce reflections at the level of the gap (*gap resonances*).

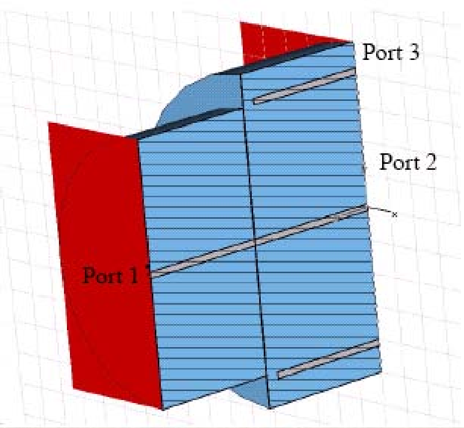


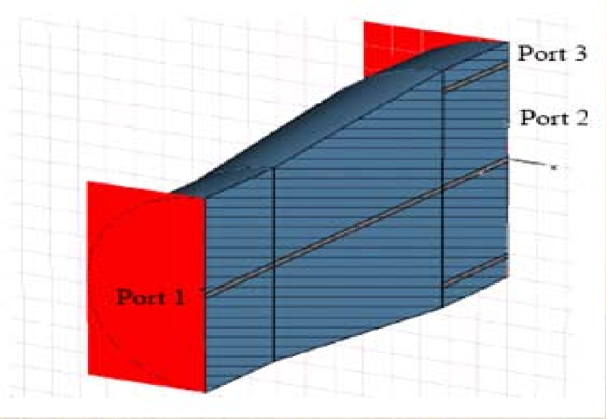
| $R_i$ (mm) | Inner coaxial radius | 20 |
|---|---|---|
| $R_o$ (mm) | Outer coaxial radius | 25 |
| $R_w$ (mm) | Internal wire radius | 0.5 |
| t (mm) | Pipe thickness | 1 |

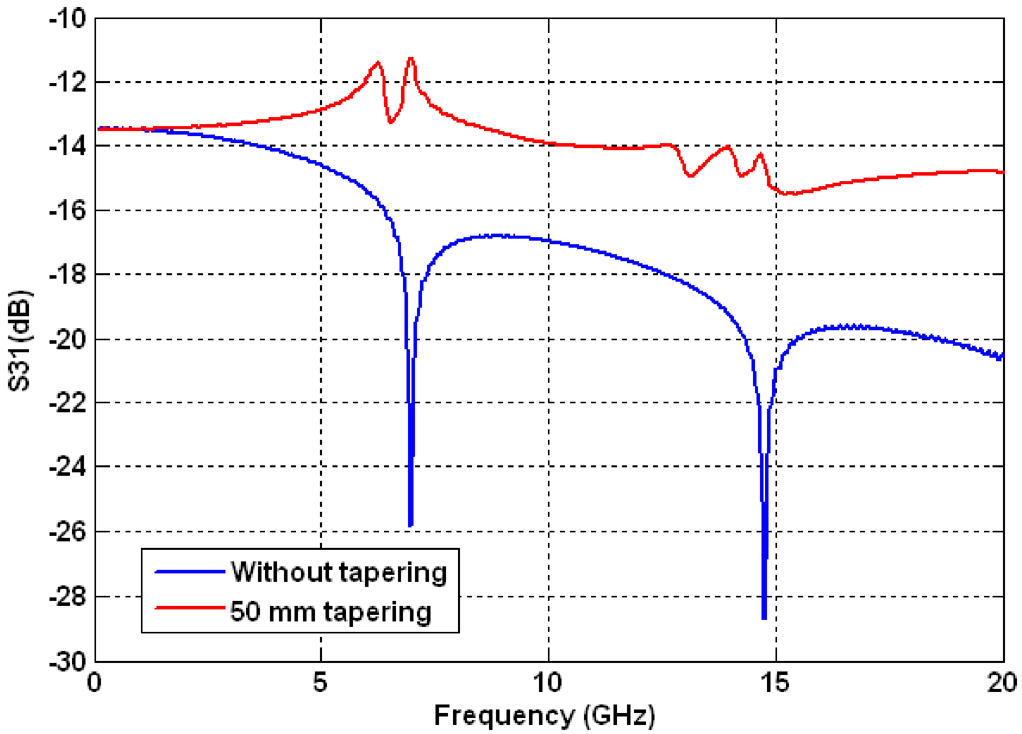


# Tapered structure

Using a tapering to smooth the gap transition:







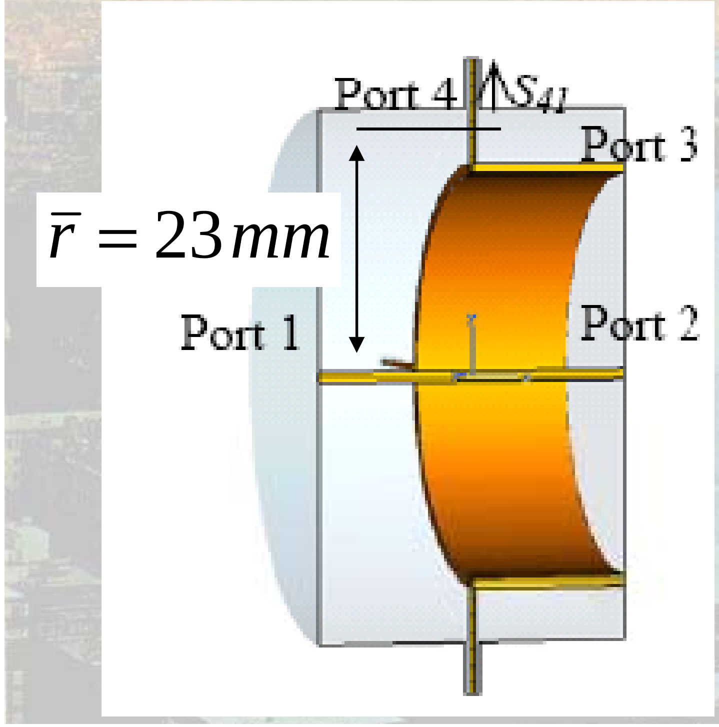
| | | |
|---|---|---|
| $R_i$ (mm) | Inner coaxial radius | 20 |
| $R_o$ (mm) | Outer coaxial radius | 25 |
| $R_w$ (mm) | Internal wire radius | 0.5 |
| t (mm) | Pipe thickness | 1 |

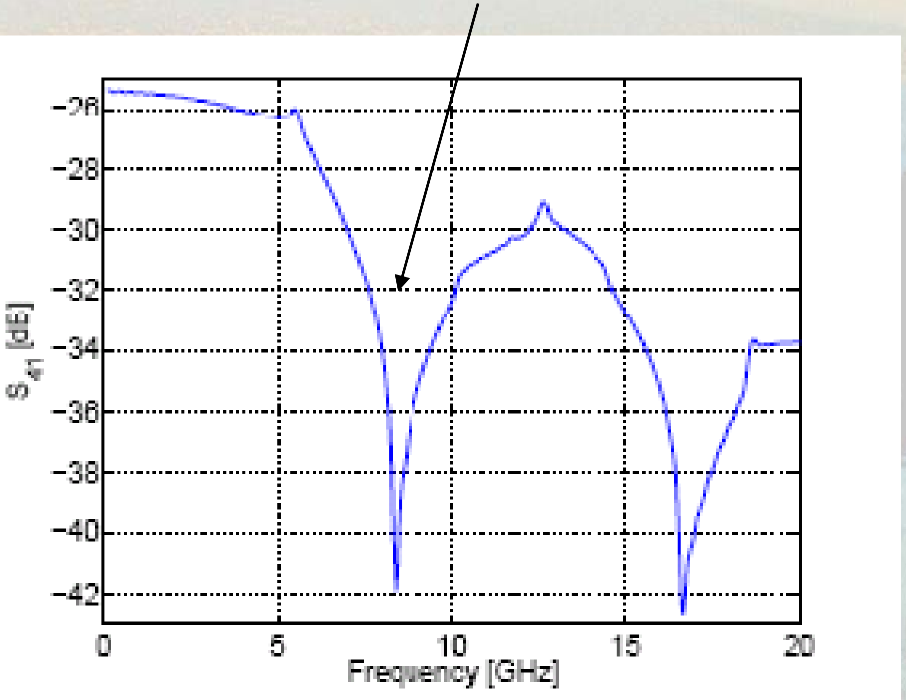
# Feedthrough resonances

When the distance between two feedthroughs becomes equal to the free space wavelength, the first azimuthal resonance appears in the structure

$$F = \frac{c}{2\pi(\bar{r}/n)} \qquad n = \text{number of feedthrough}$$

**With *n* =4, one has *F* =8.3 GHz**

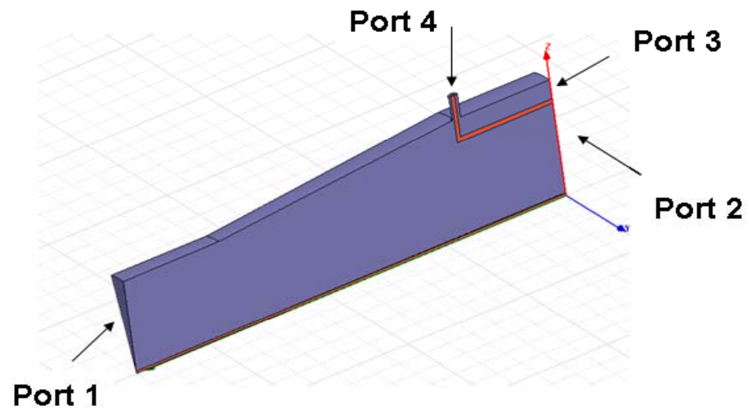


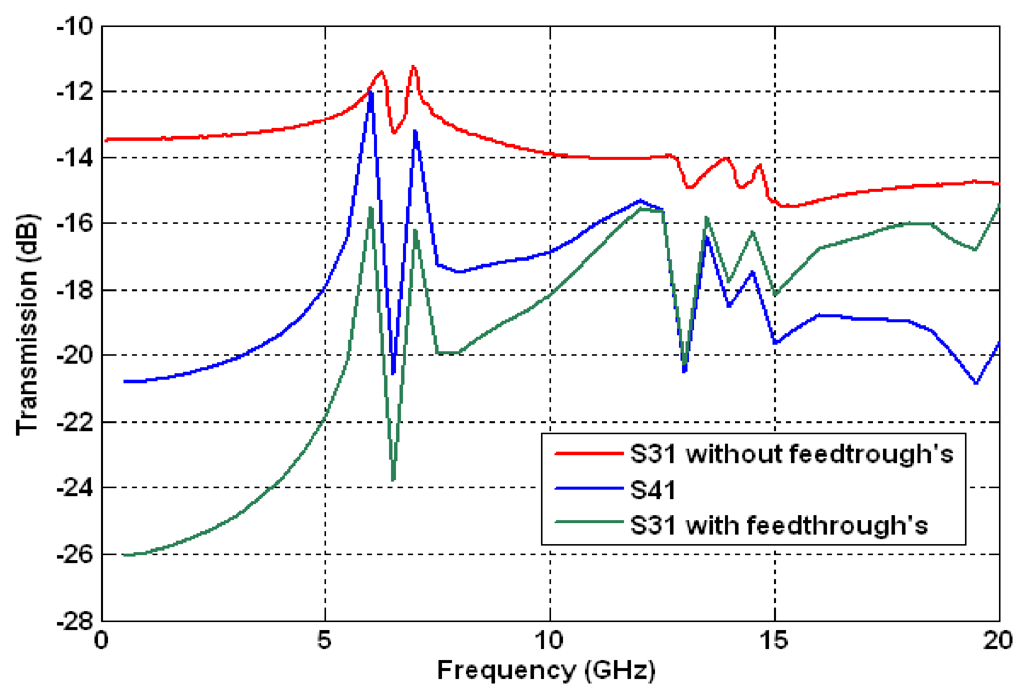


**With the courtesy of Tom Kroyer ("*A Structure for a Wide Band Wall Current Monitor*", AB-Note-2006-040 RF)**

# The whole structure

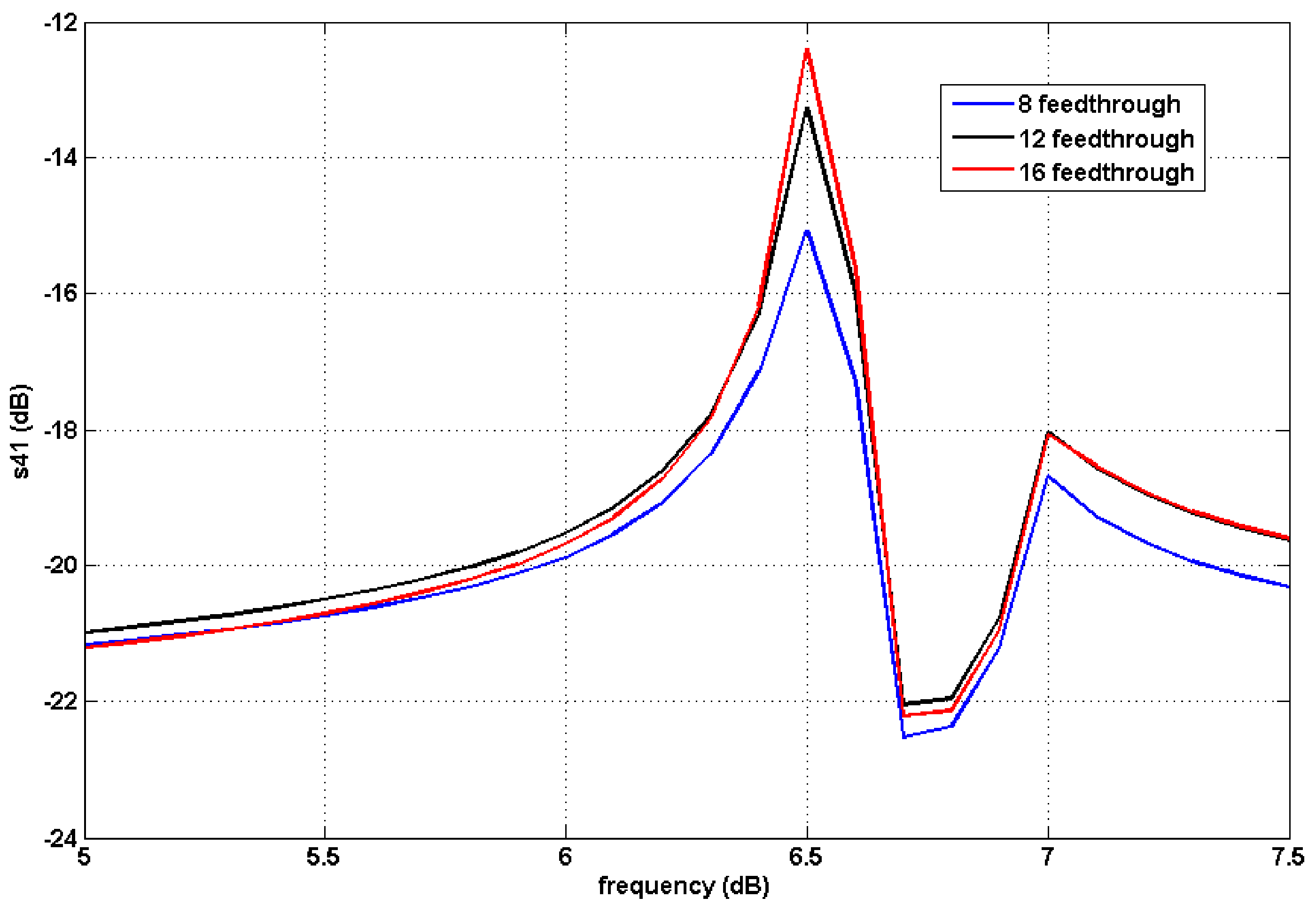
Therefore to have 16 feedthroughs means to push the previous resonance to ≅ 33 GHz

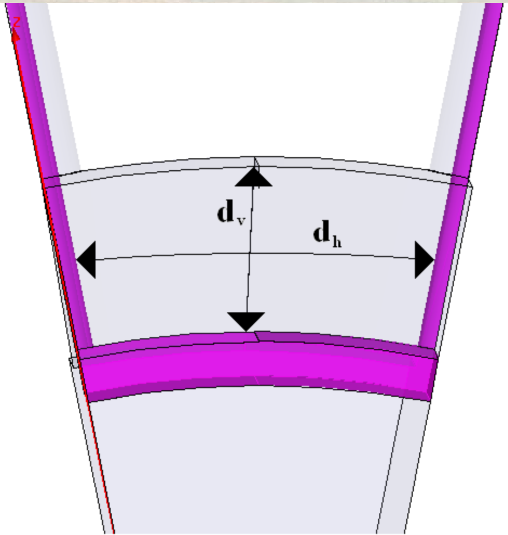




The presence of the feedthrough's prevents the modes to freely pass from the inner to the outer pipe. To reproduce the same results of a structure without feedthrough's one should fulfill the following condition

$$d_{feed} = \frac{2\pi}{n} r \geq \lambda_{TM01_{cutoff}}$$

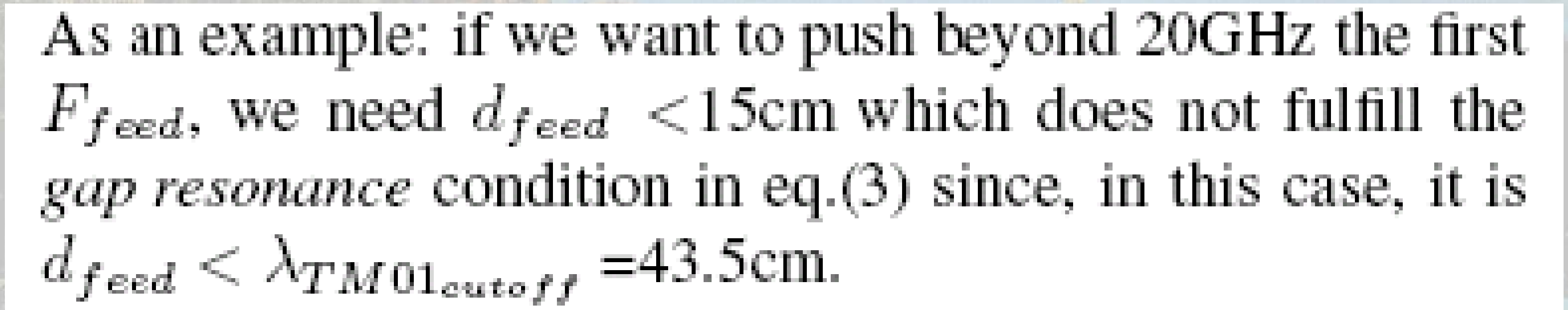




# Final Constraints

*Feedthrough resonance* *Gap resonance*

$$F_{feed} = \frac{c}{d_{feed}} \qquad d_{feed} \geq \lambda_{TM01_{cutoff}} \quad (3)$$



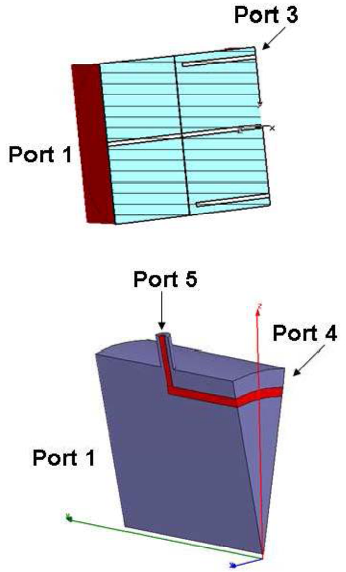
As an example: if we want to push beyond 20GHz the first $F_{feed}$, we need $d_{feed}$ <15cm which does not fulfill the *gap resonance* condition in eq.(3) since, in this case, it is $d_{feed} < \lambda_{TM01_{cutoff}}$ =43.5cm.

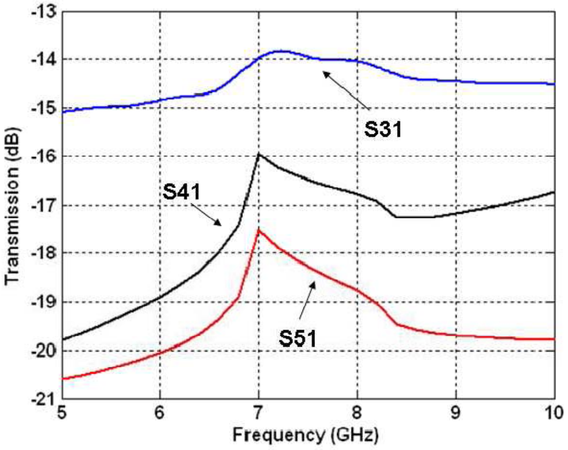
# *The solution*

**It is possible to overcome the impasse on the $d_{feed}$ value in two ways:**

1. **by reducing the outer pipe aperture to a reasonable quantity, in order to permit the gap resonances excited at its edge to run back in the beam pipe;**
2. **by playing with the field configurations of a double coaxial waveguide, in order to avoid the gap resonance enhancement.**

## Solution 1

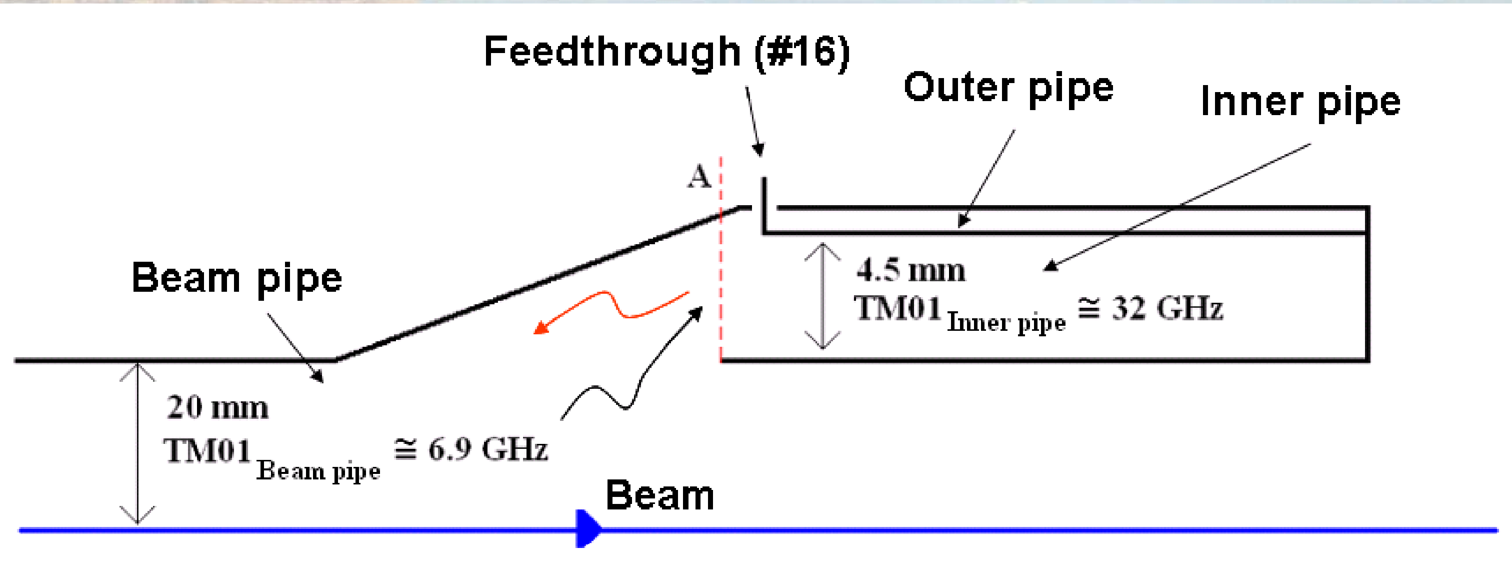




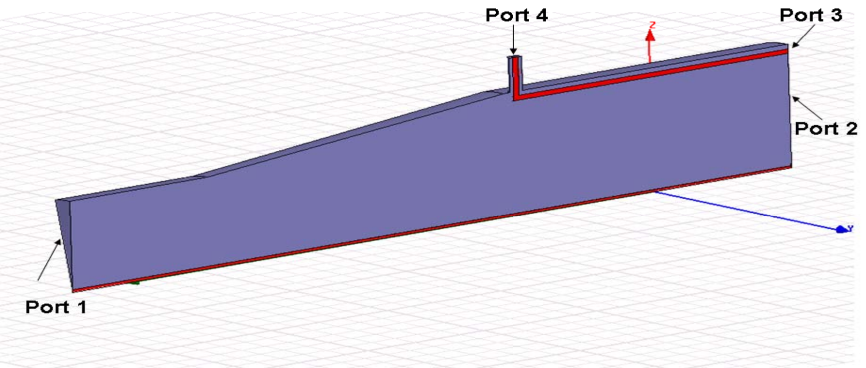
Comparison between a structure with a 2mm aperture reduction with and without feedthrough’s; in this case the number of feedthrough’s is 8 giving the first feedthrough resonance at ≅ 20GHz.

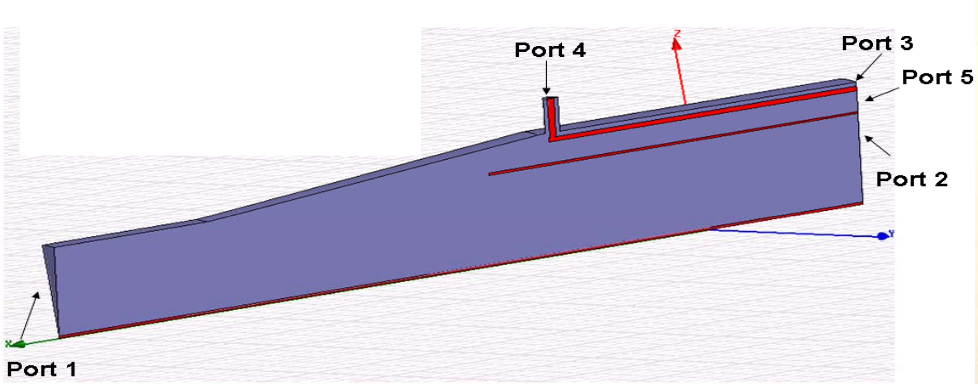
# Solution 2: Working Principle

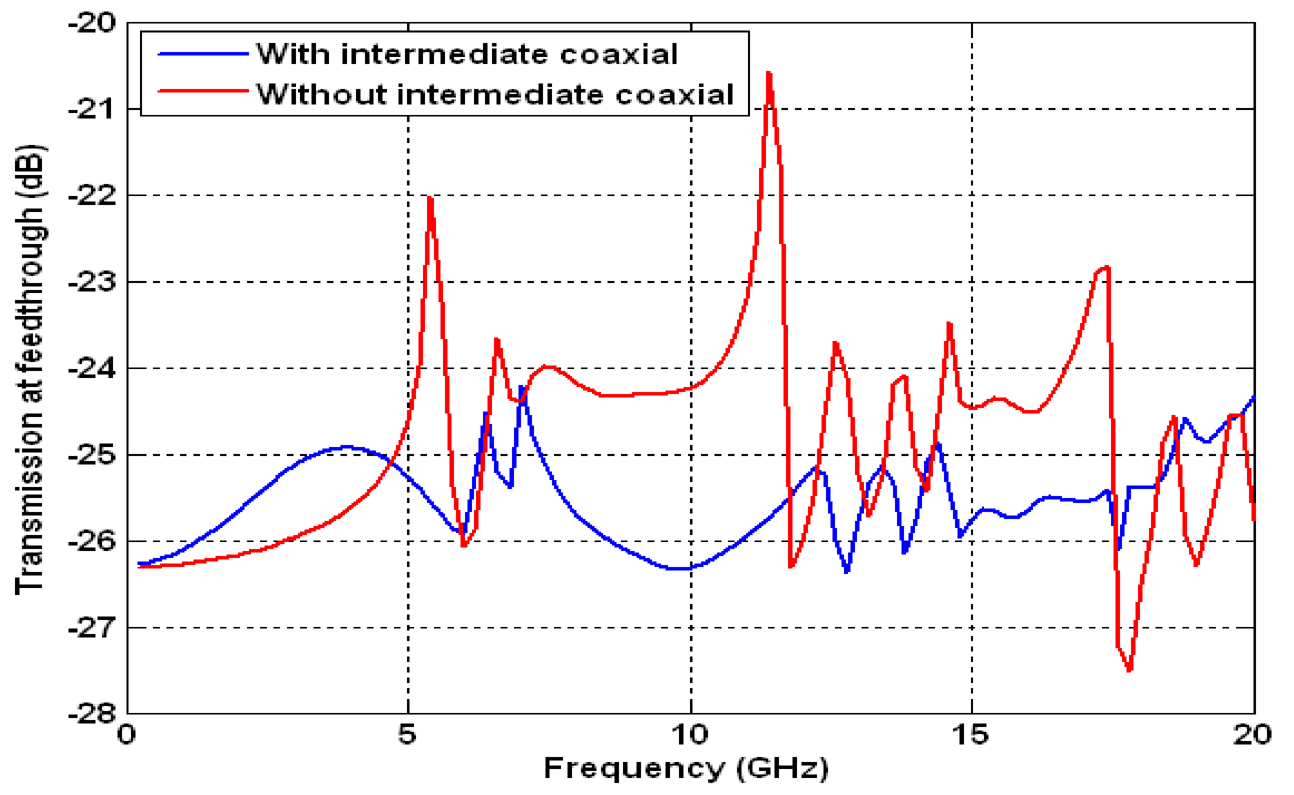
**The intermediate pipe (inner pipe in the figure) reflects back at the surface *A* the TM modes coming from the beam pipe, and thus *shields* the feedthrough's and avoids the enhancement of the reflections**



# Solution 2: Simulations

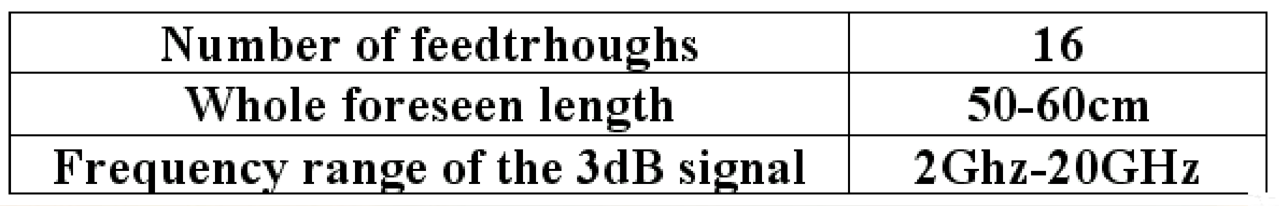




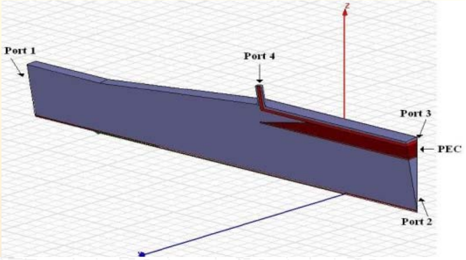


# Three possible structures found

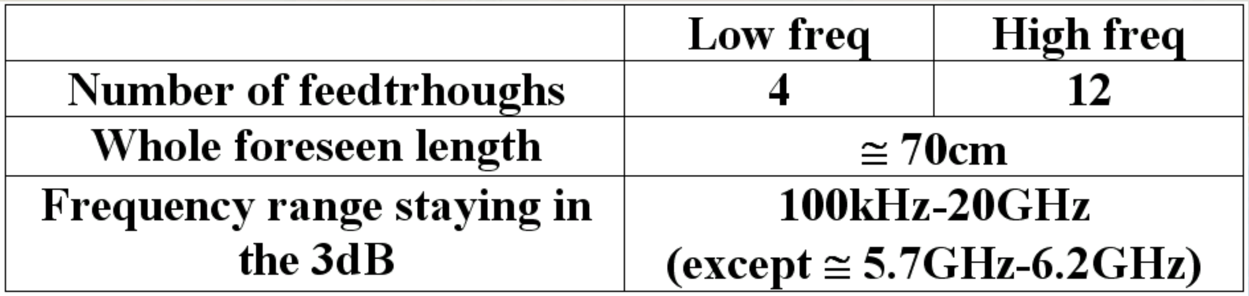
**1.**



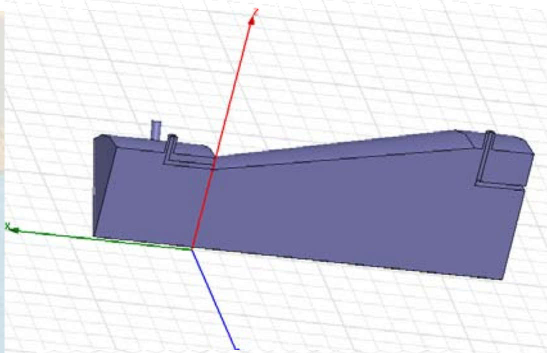
| Number of feedtrhoughs | 16 |
|---|---|
| Whole foreseen length | 50-60cm |
| Frequency range of the 3dB signal | 2Ghz-20GHz |



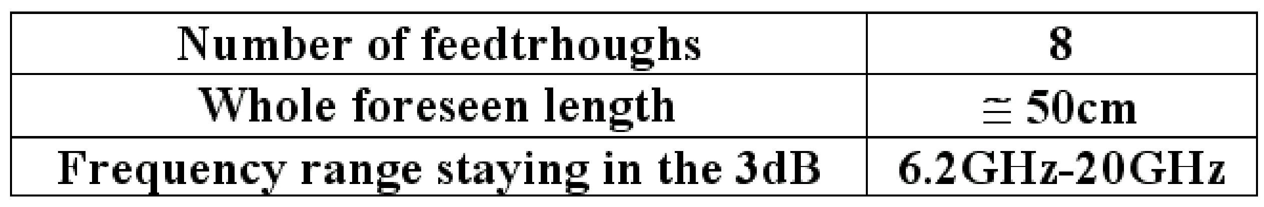
**2.**



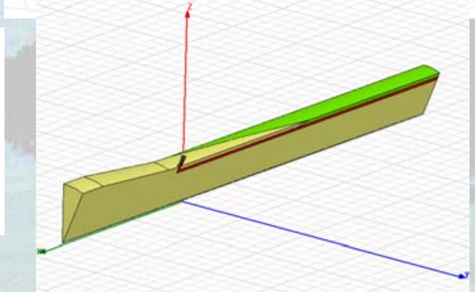
| | Low freq | High freq |
|---|---|---|
| Number of feedtrhoughs | 4 | 12 |
| Whole foreseen length | ≅ 70cm | |
| Frequency range staying in the 3dB | 100kHz-20GHz (except ≅ 5.7GHz-6.2GHz) | |



**3.**



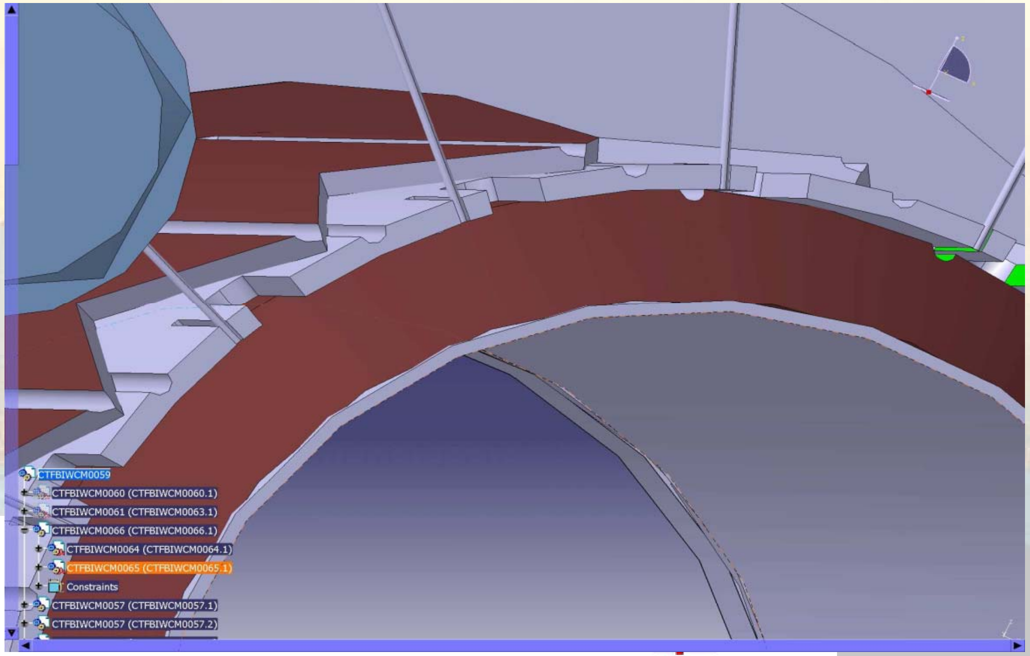
| Number of feedtrhoughs | 8 |
|---|---|
| Whole foreseen length | ≅ 50cm |
| Frequency range staying in the 3dB | 6.2GHz-20GHz |

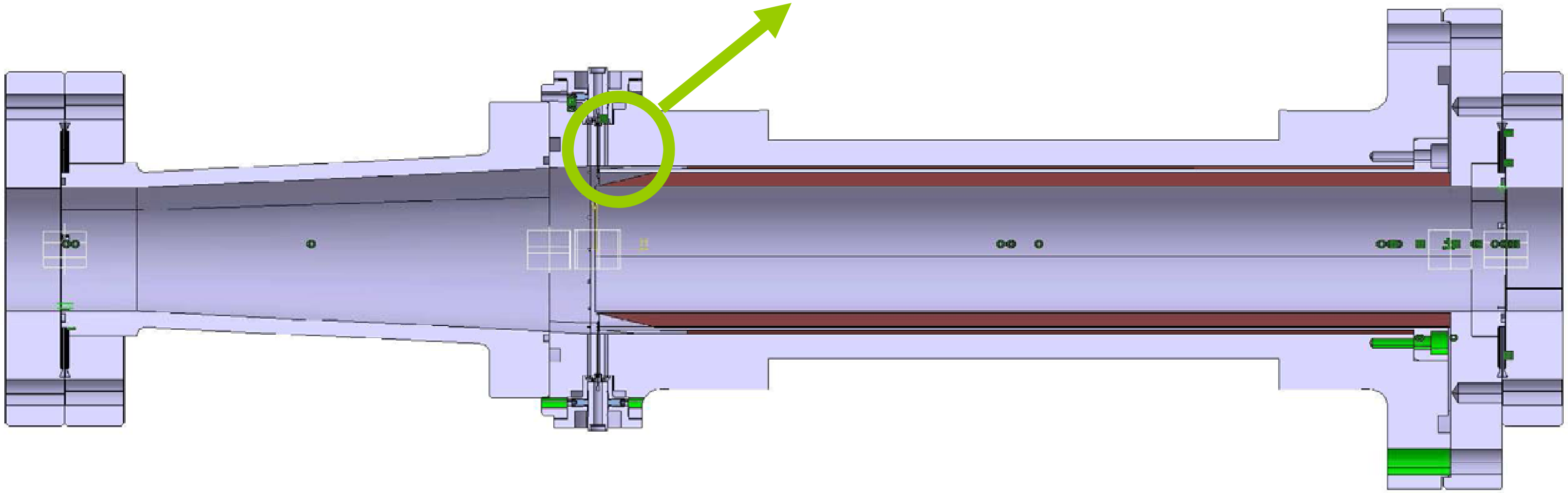


**The last two structures present an aperture reduction of 15% and 30%, respectively. For that reason the first one has been chosen.**

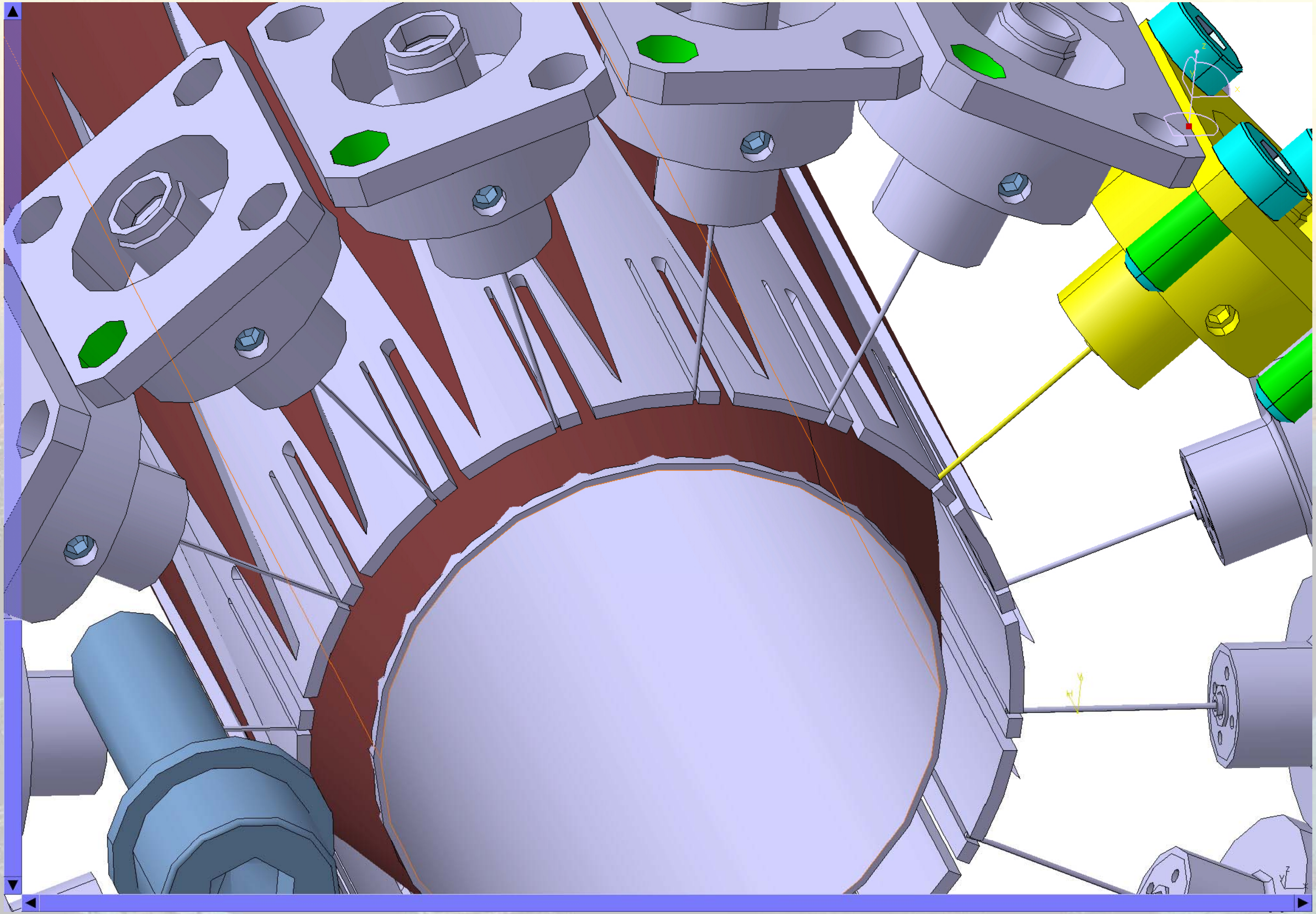
# The Final Structure

In order to absorb the e-m radiation going into the inner and outer pipes, two layers of SiC have been used



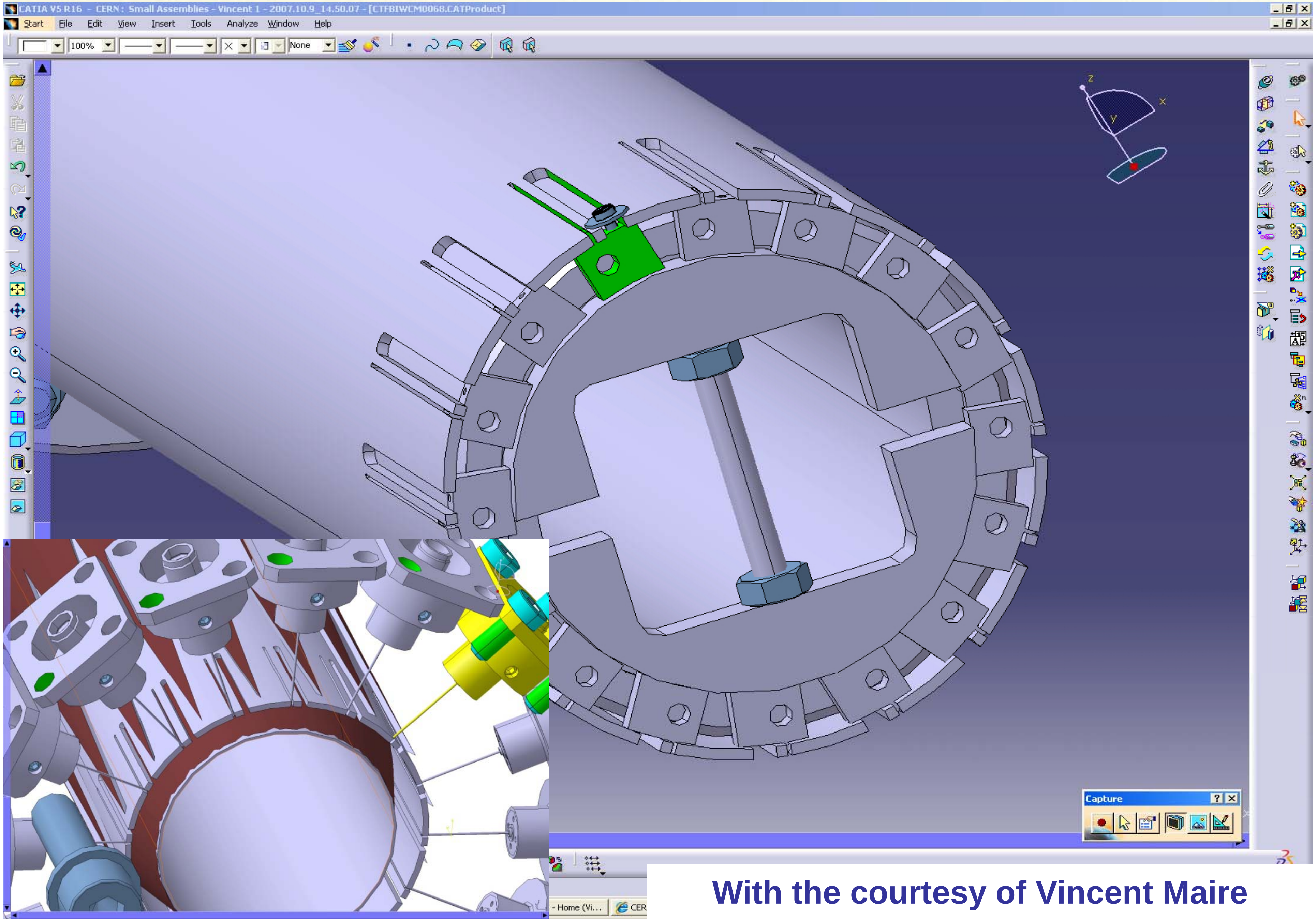


# Feedthrough positioning (1)

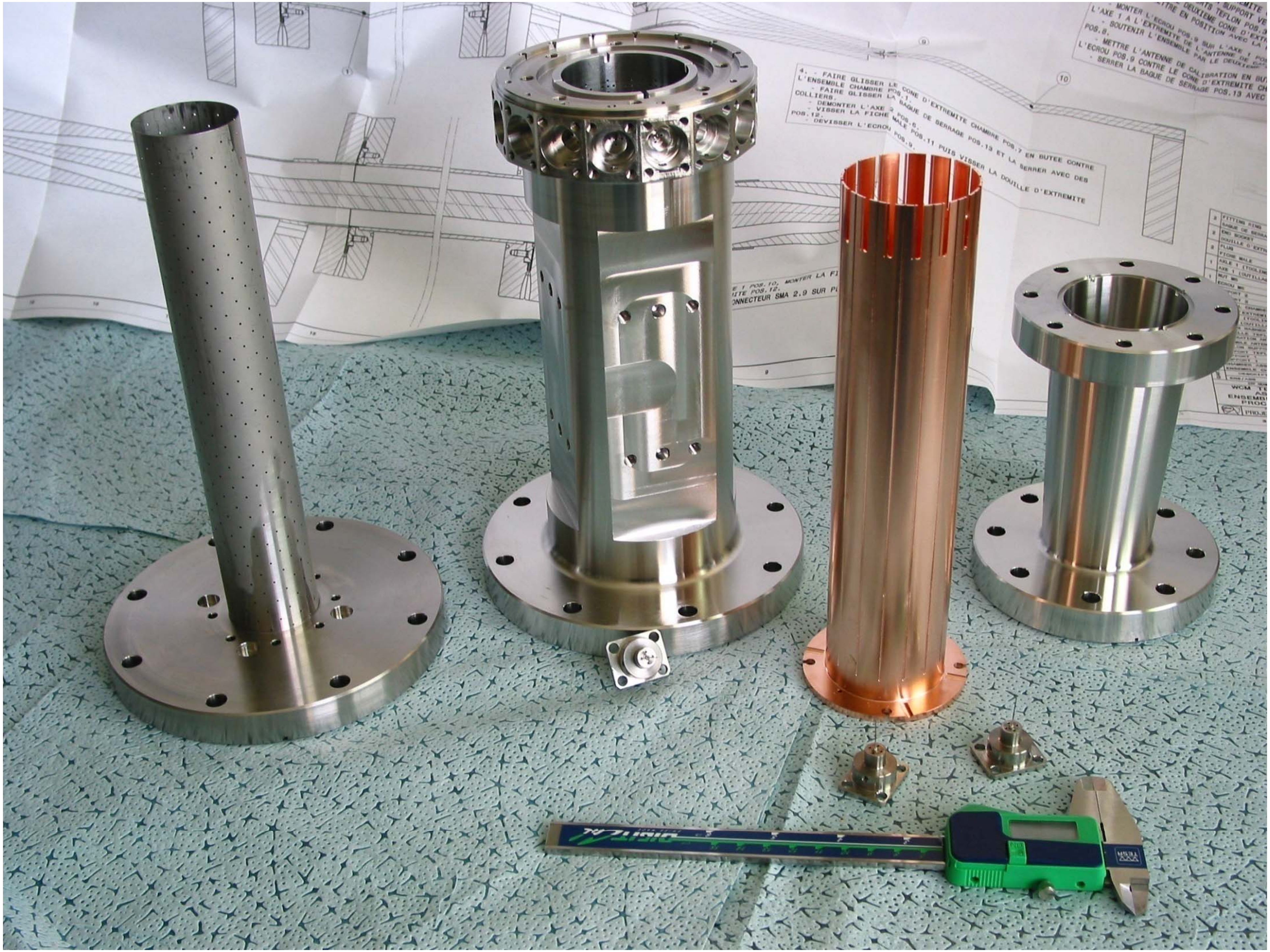


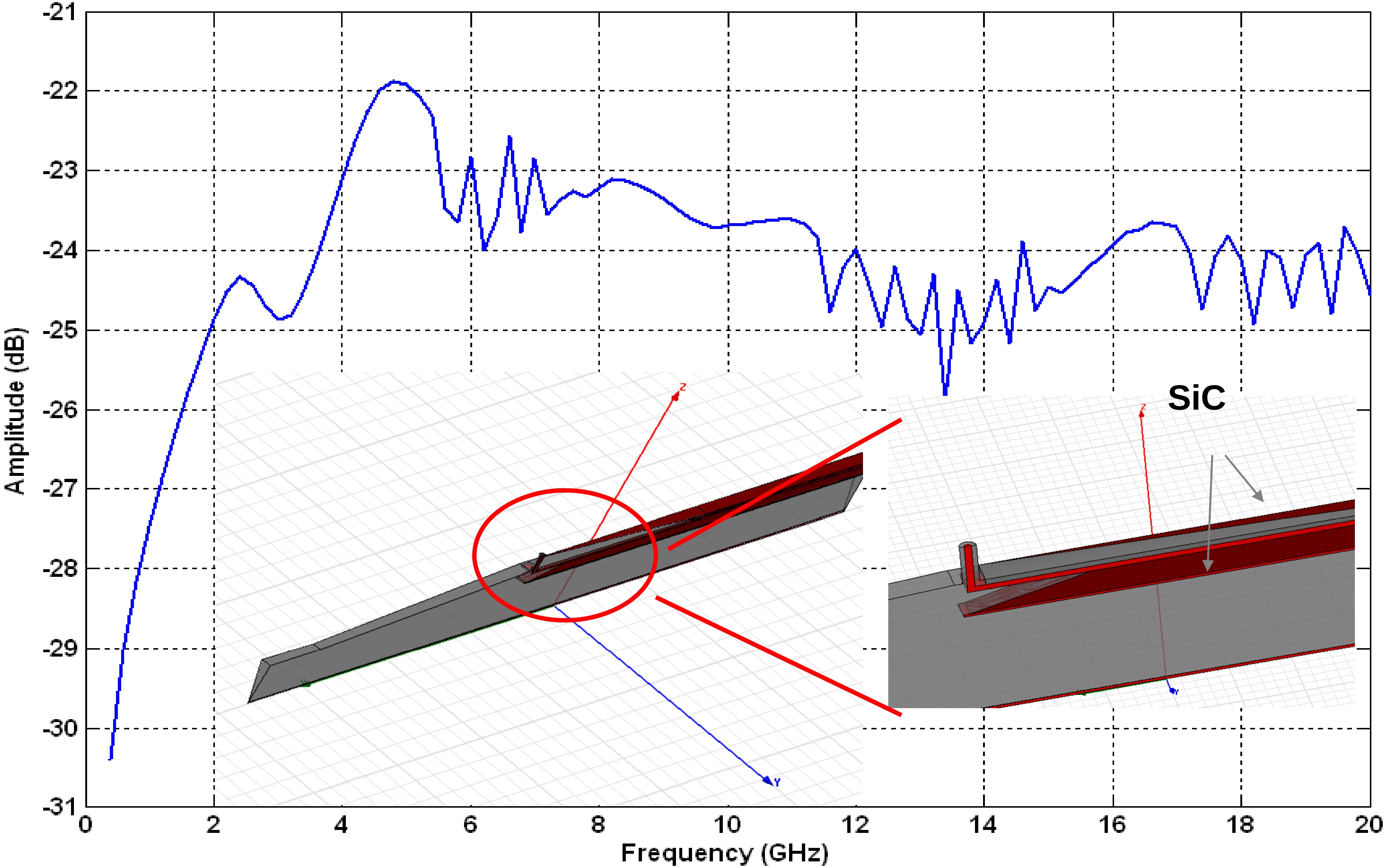
With the courtesy of Vincent Maire

# Feedthrough positioning (2)



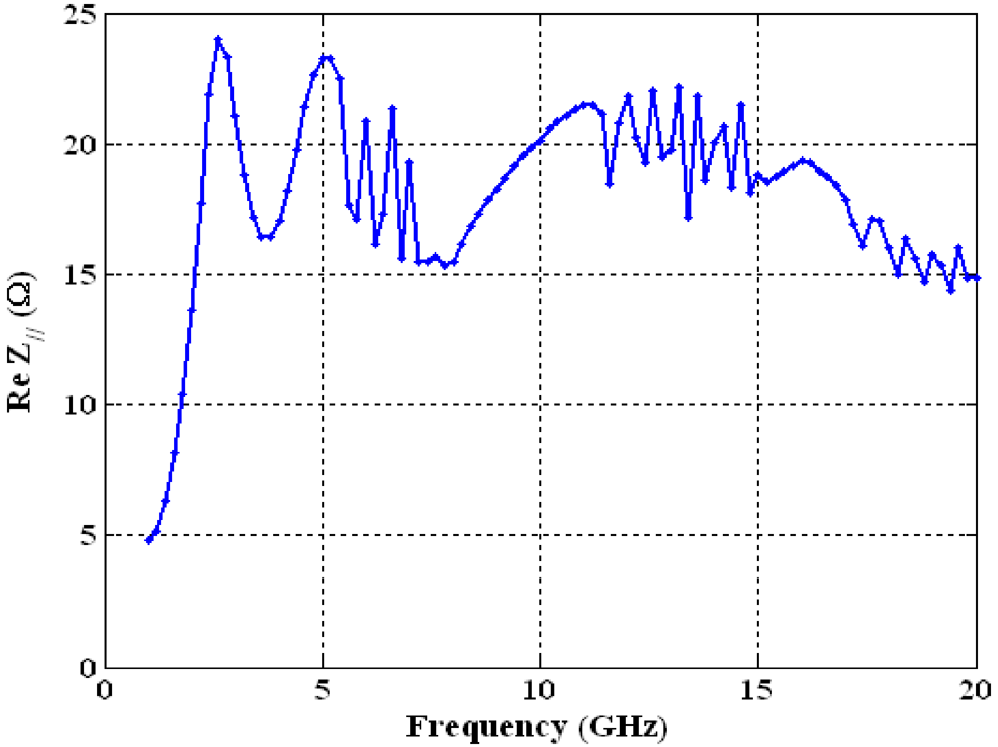
**With the courtesy of Vincent Maire**

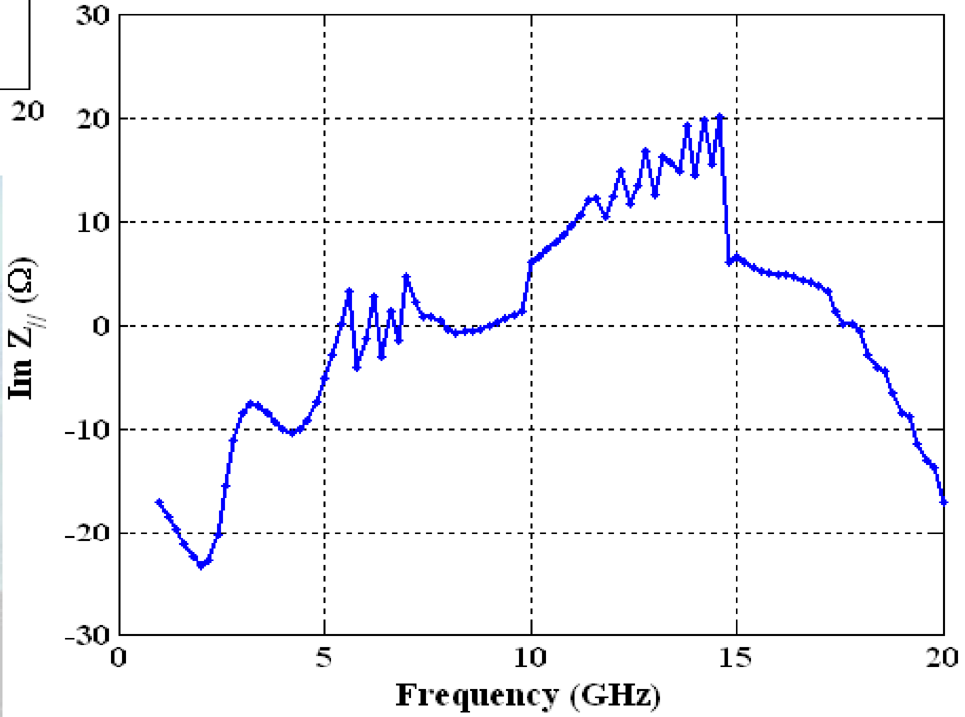

4. - FAIRE GLISSER LE CONE D'EXTREMITE CHAMBRE POS.7 EN BUTEE CONTRE L'ENSEMBLE CHAMBRE POS.1.
- FAIRE GLISSER LA BAGUE DE SERRAGE POS.13 ET LA SERRER AVEC DES COLLIERS.
- DEMONTER L'AXE 2 POS.6.
- VISSER LA FICHE MALE POS.11 PUIS VISSER LA DOUILLE D'EXTREMITE POS.12.
- DEVISSER L'ECROU POS.9.
9
10



The simulations show a good signal staying in ± 2dB around -24dB in a range of frequency from 2GHz to 20GHz with the possibility of lowering it down to 400MHz by means of external circuits.

# The Longitudinal Impedance



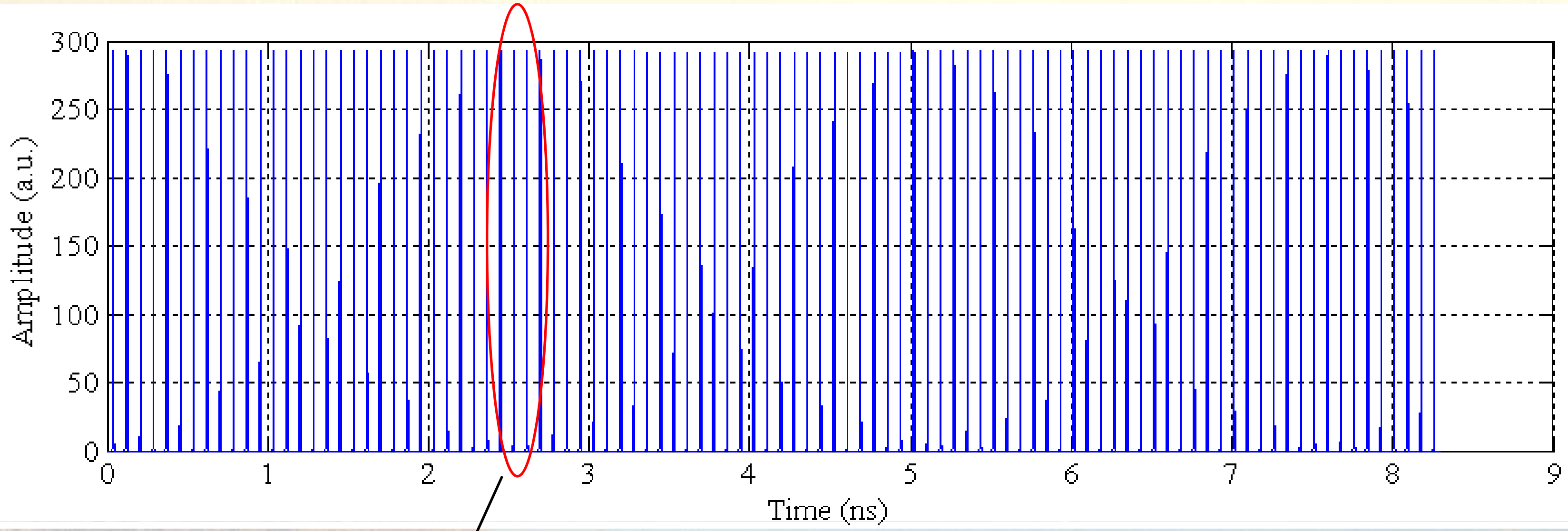


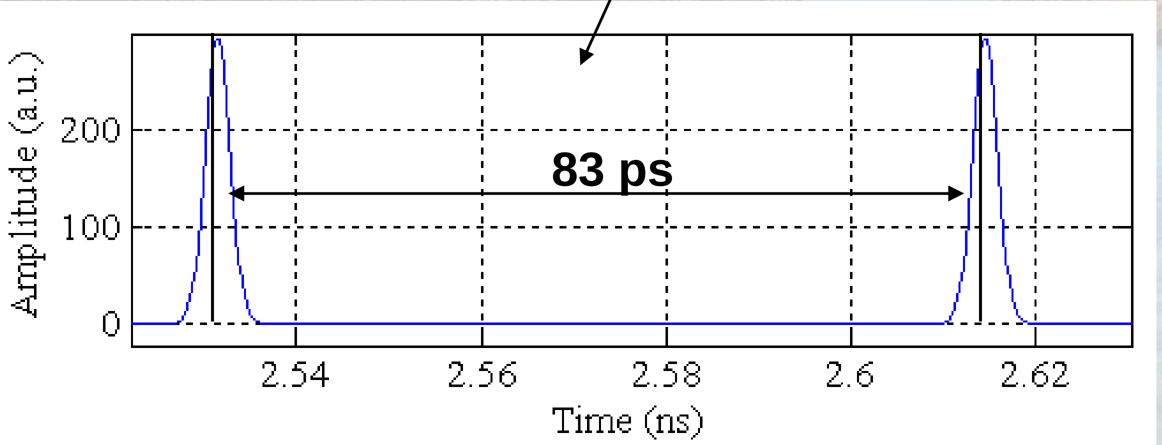
# Really do we need 100kHz low freq cut-off?

The request of 100kHz low frequency cutoff comes from the very long bunch pulse of 1.54μs (namely ≈700kHz) of CTF3 drive beam Linac. The effect of a higher low frequency cutoff is to give an exponential droop of the signal with a time constant $\tau_L = 1/3f_{low}$, where $f_{low}$ is the low frequency cutoff. This effect could be dangerous if the droop constant time $\tau_L$ is comparable or lower than the bunch length in time which is not the case since the r.m.s. expected bunch lengths for ILC and CLIC are of 1ps and 3.33ps, respectively.

**A more serious problem is the possible influence of the low frequency cutoff for a proper signal recovering**

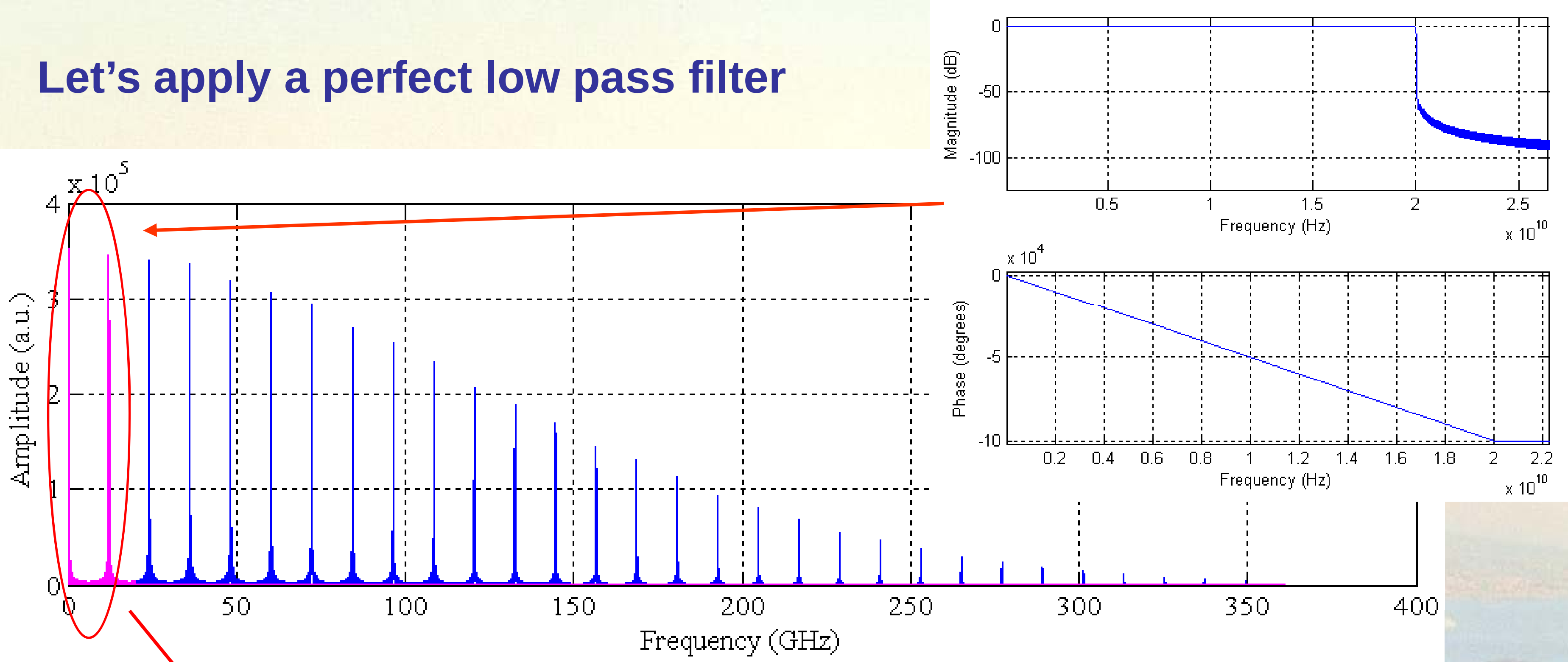
# CLIC Drive Beam

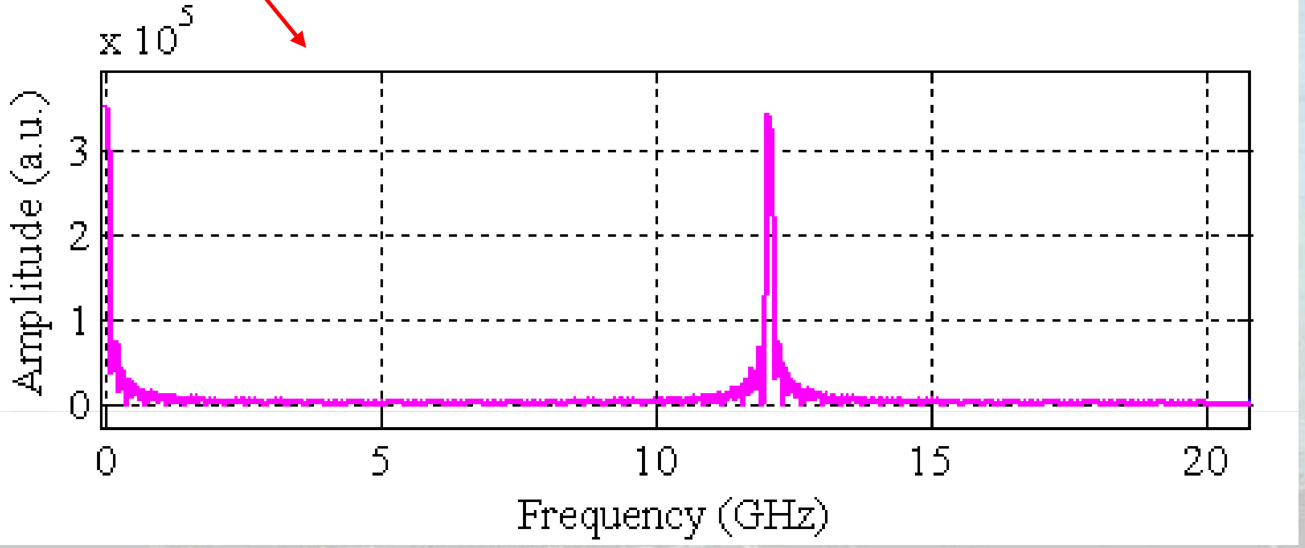




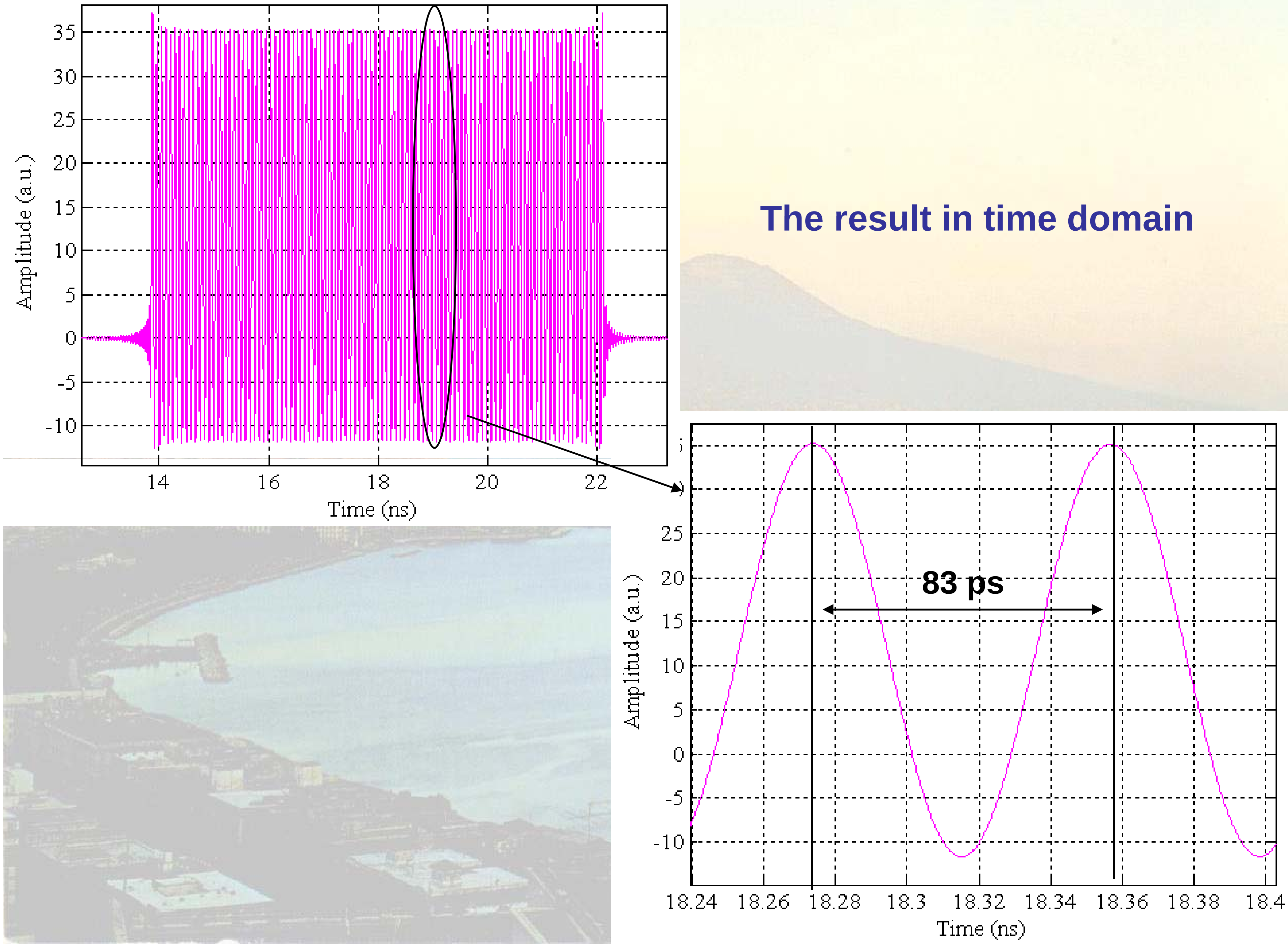
**Bunch separation = 83ps**
**RMS bunch length = 13.3ps**
**Train duration = 8.3ns**
**Nb of bunches = 100**
**Peak current = 293A**

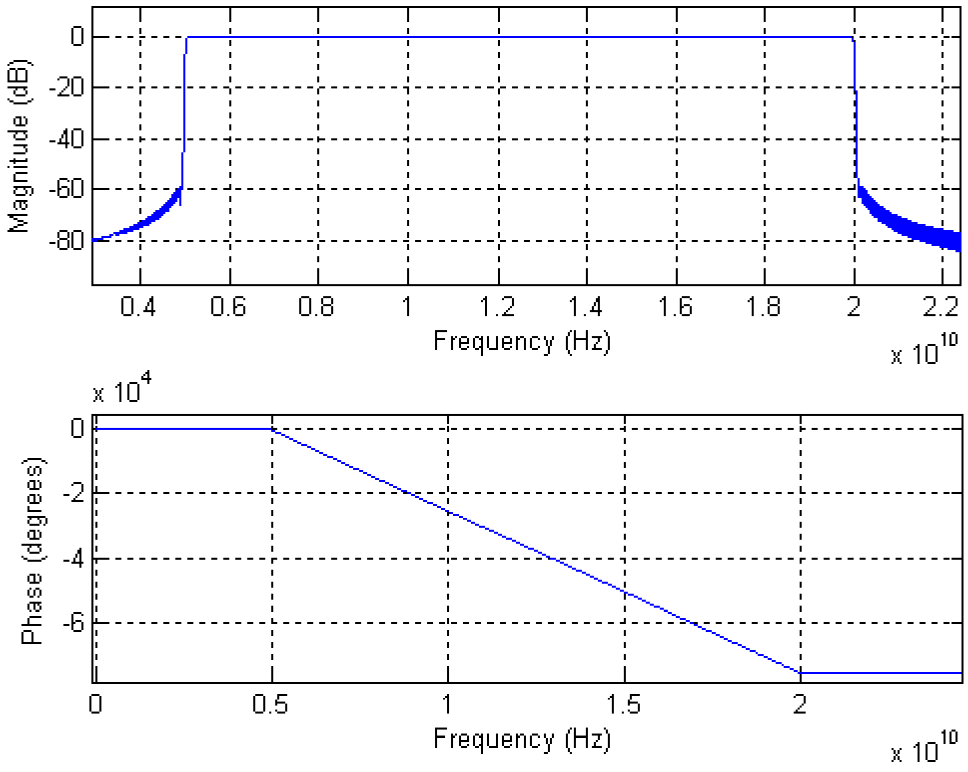
# Let’s apply a perfect low pass filter





## The result in time domain

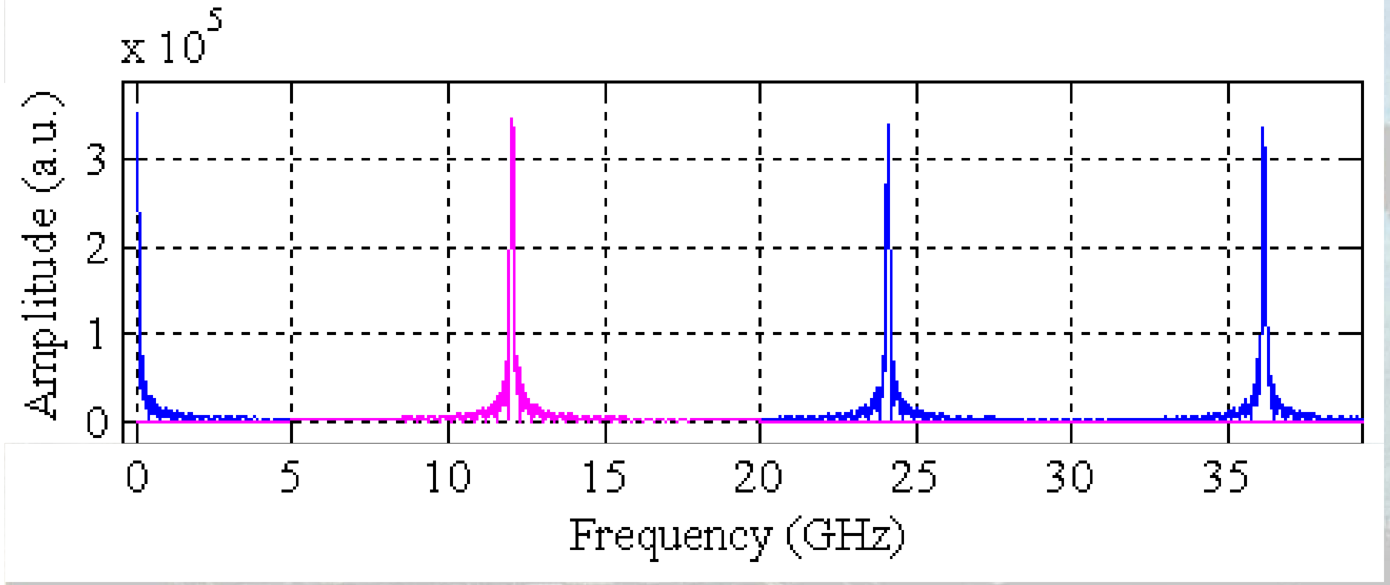


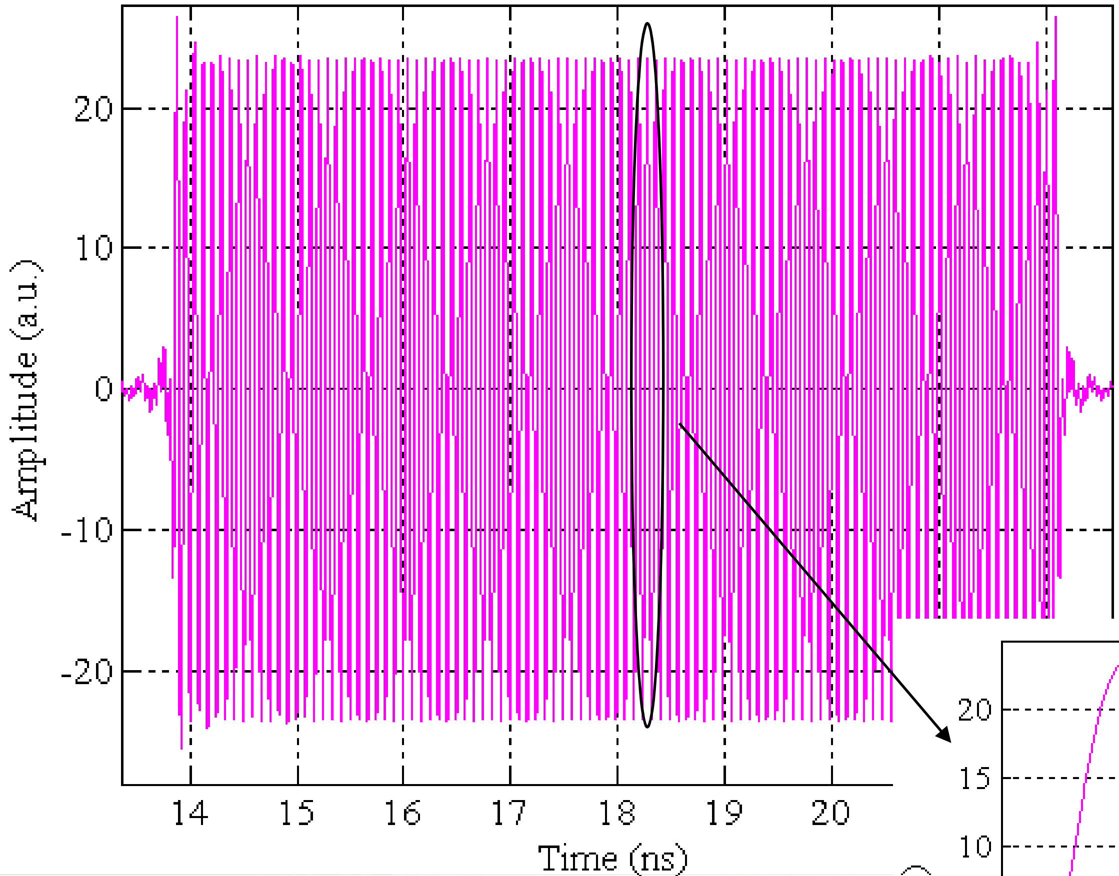


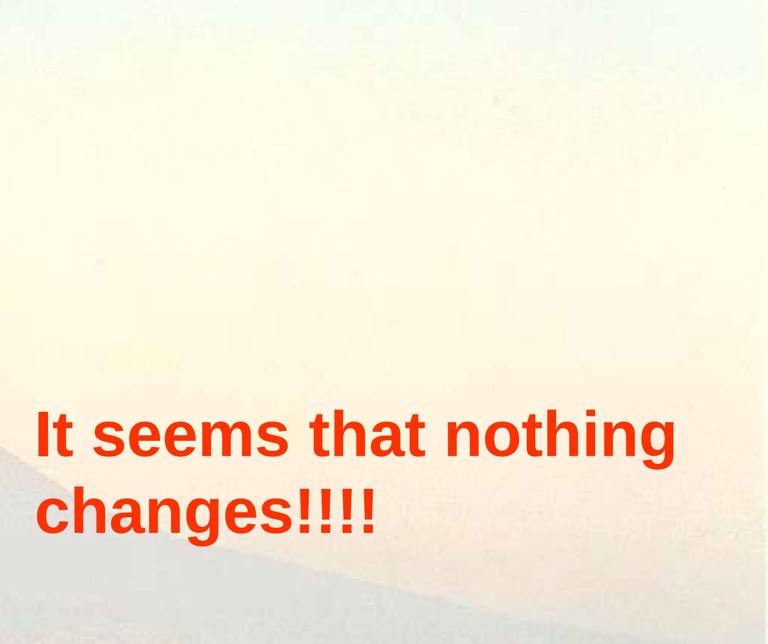
**Let's apply, to the same signal as before, a filter having**

Low freq cut-off= 5GHz

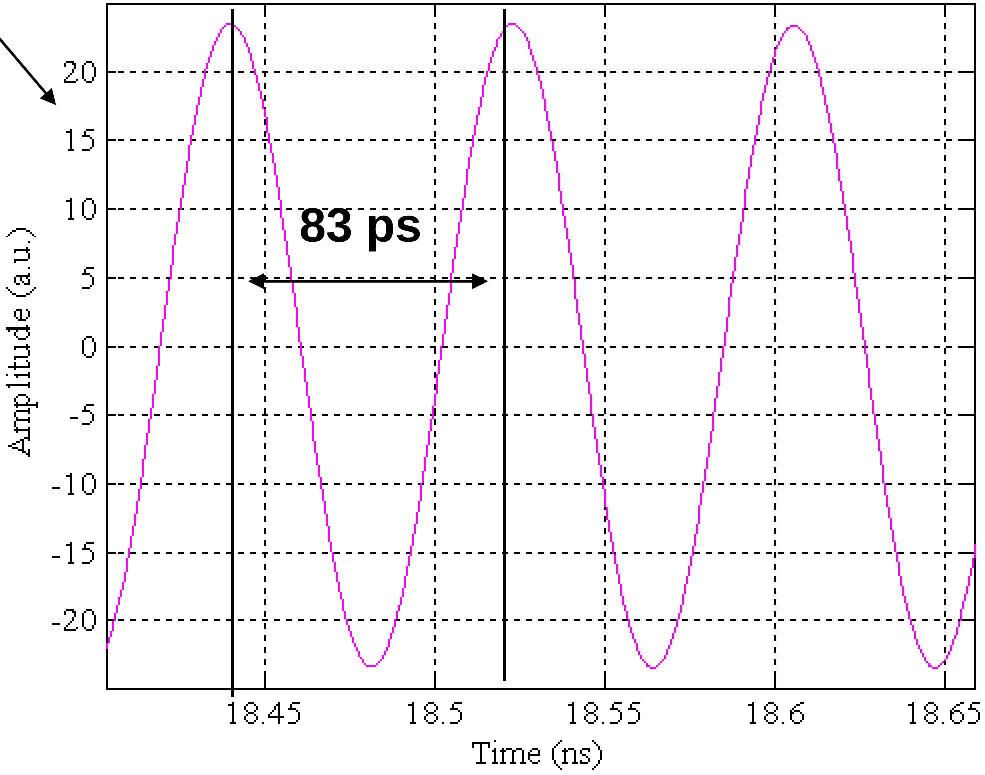
High freq cut-off= 20GHz



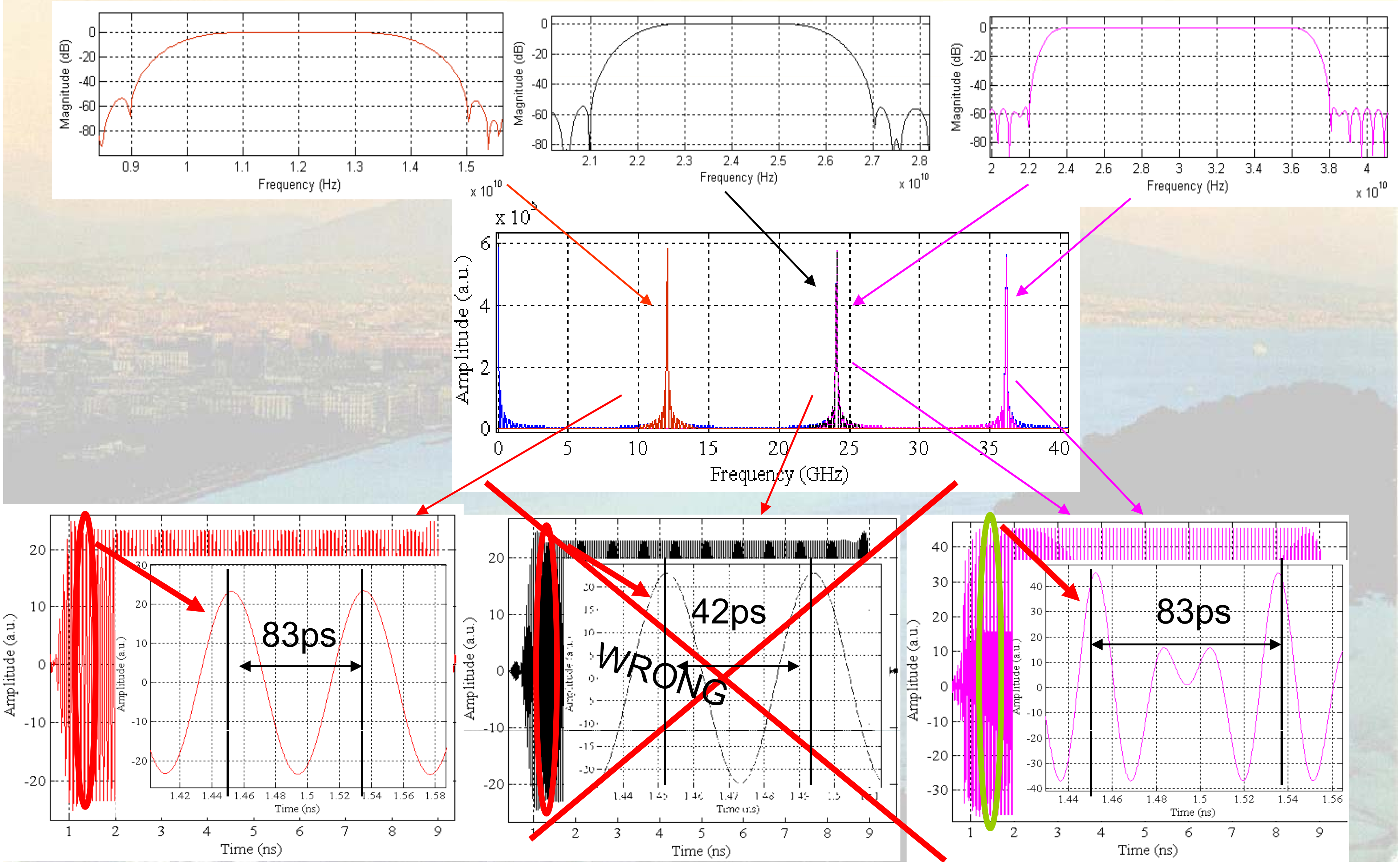




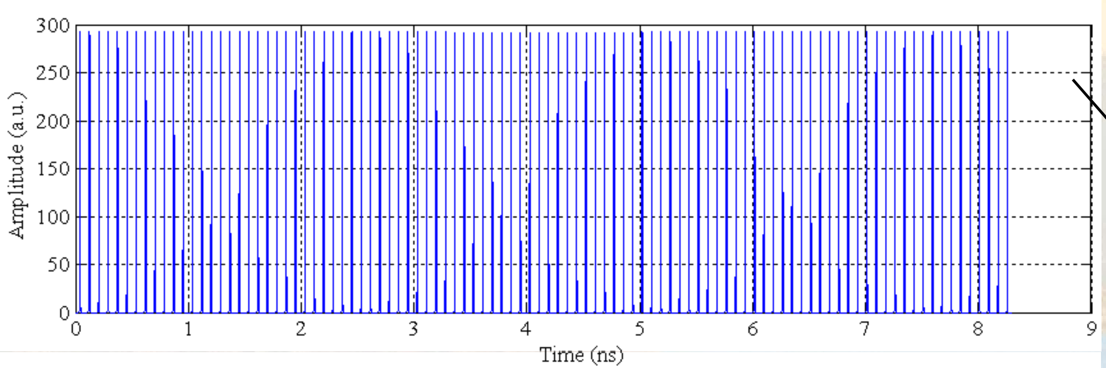
**It seems that nothing changes!!!!**

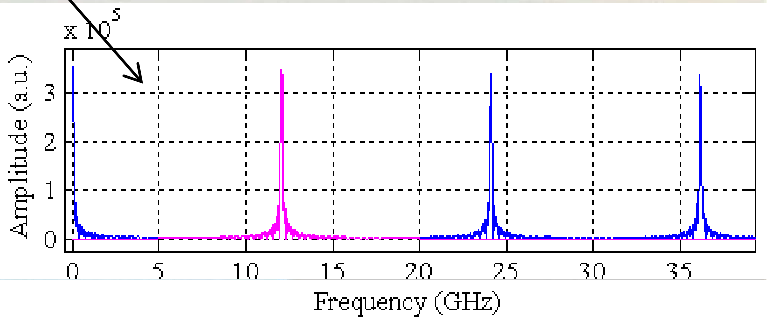


## A correct signal recovering will happen if one is able to detect the first harmonic peak or at least two adjacent peaks in the spectrum at higher frequencies.

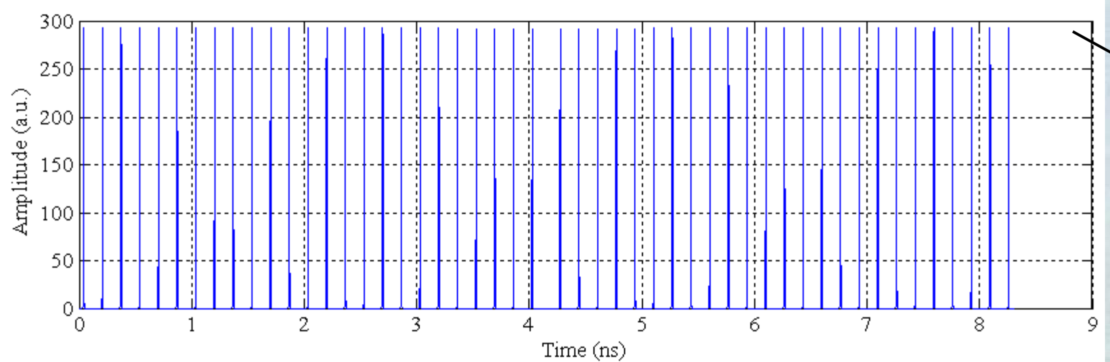


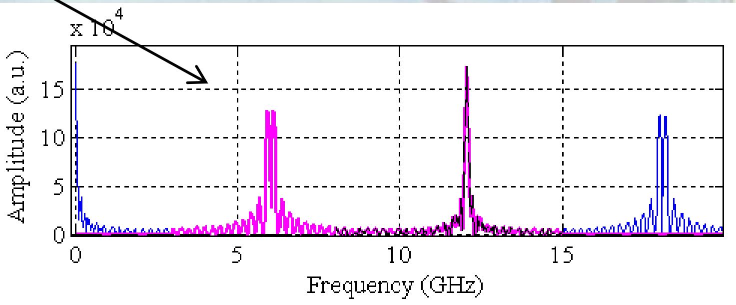
If a certain number of bunches are periodically lost the new spectrum will present the first harmonic at a lower frequency and a shorter frequency separation between the harmonic peaks (larger bunch separation in time). Therefore the merit figure for the signal recovering is the bandwidth which should be able to follow this frequency shift.



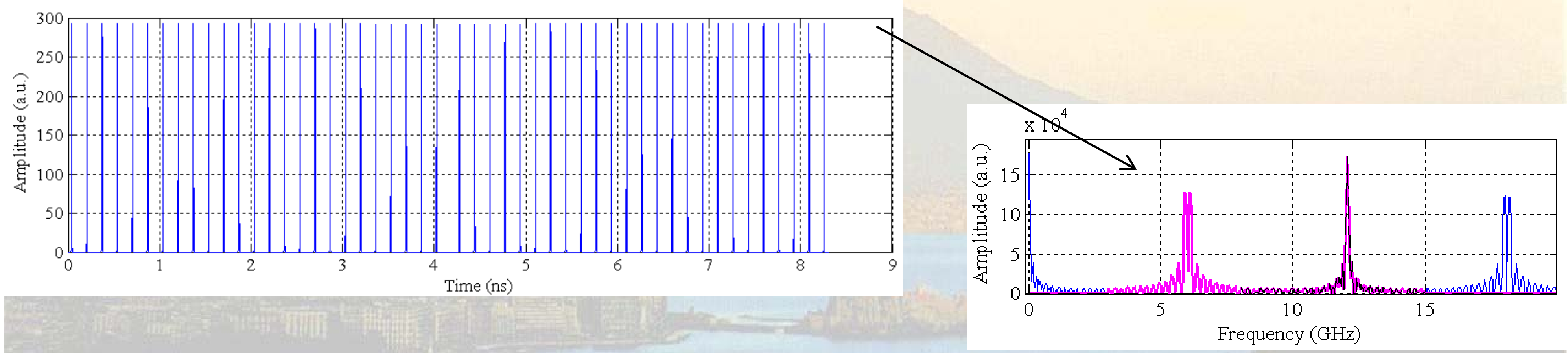


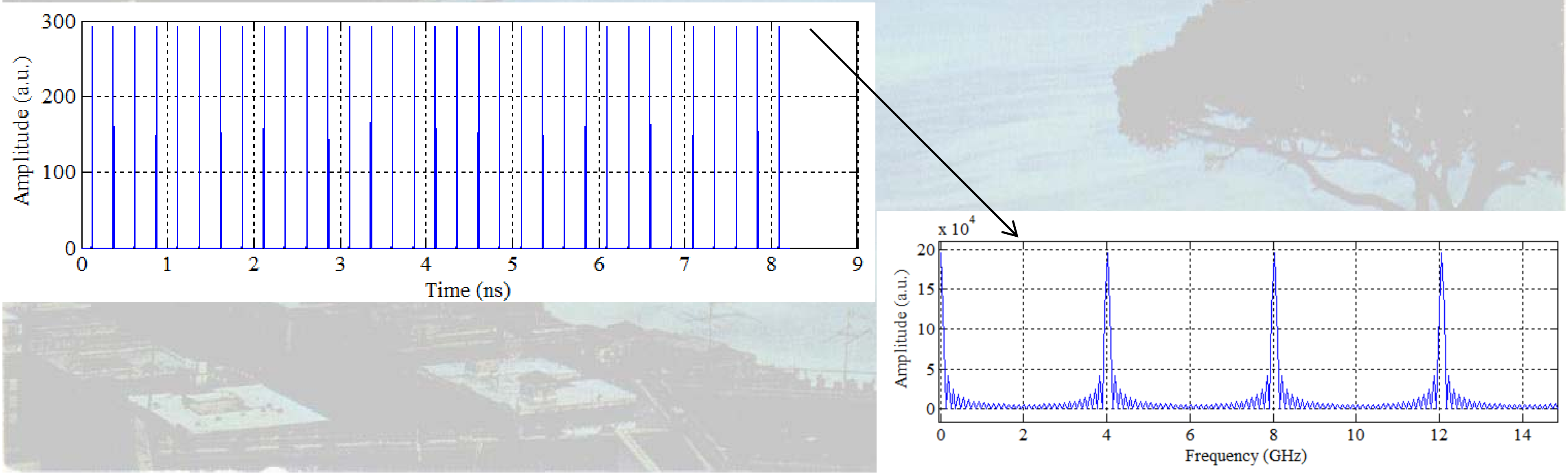
Same condition of before, but 50% of bunches are missed



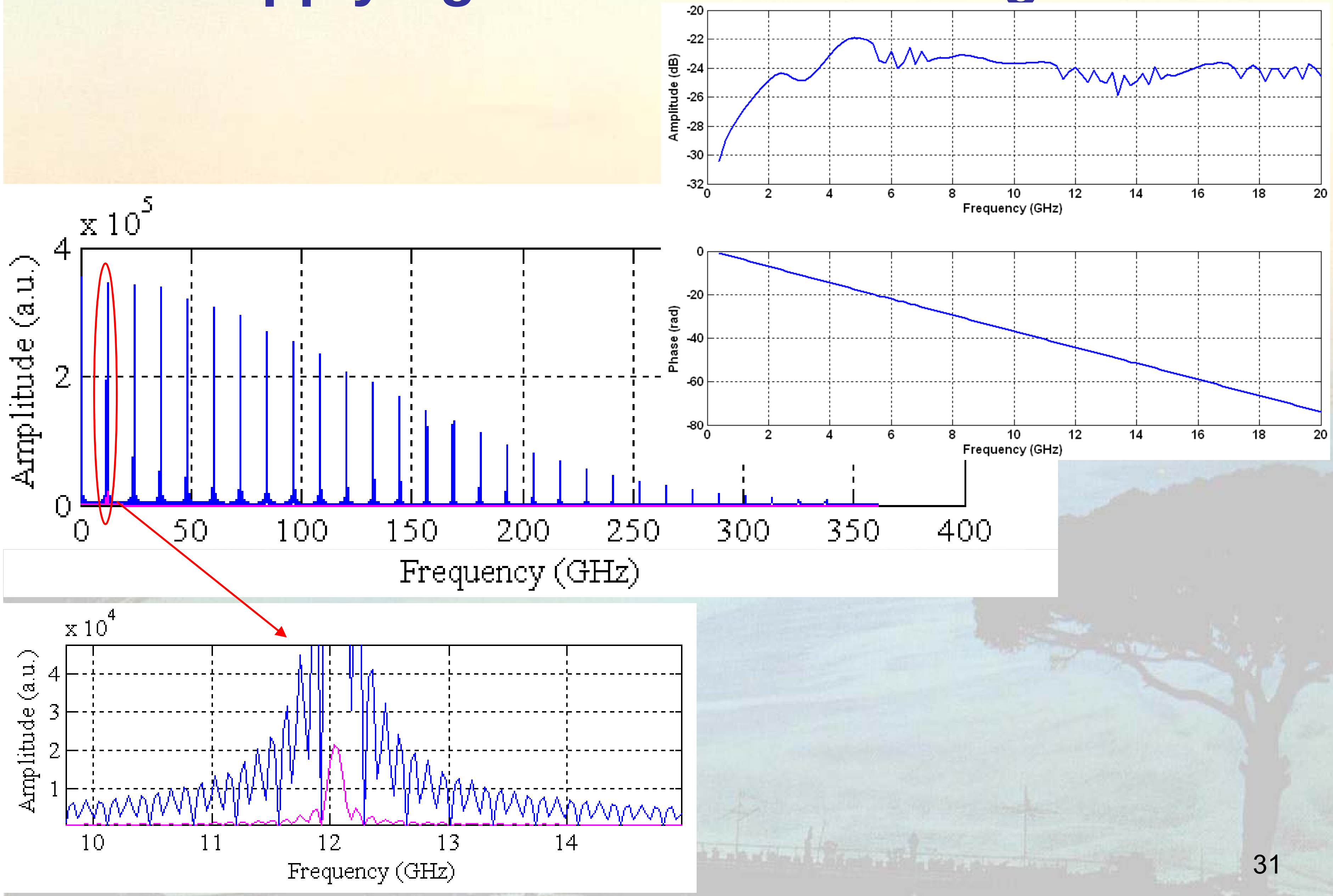


The minimum required bandwidth is fixed by one half of the highest frequency that we want to detect. In our case the minimum required bandwidth is of 6GHz determined by CLIC Drive Beam with its 83ps of bunch spacing (12GHz) representing the worst condition since the bunch spacing for the CLIC Main Beam is 500ps (≈2GHz) while for ILC beams it is 369.2ns (≈3MHz).

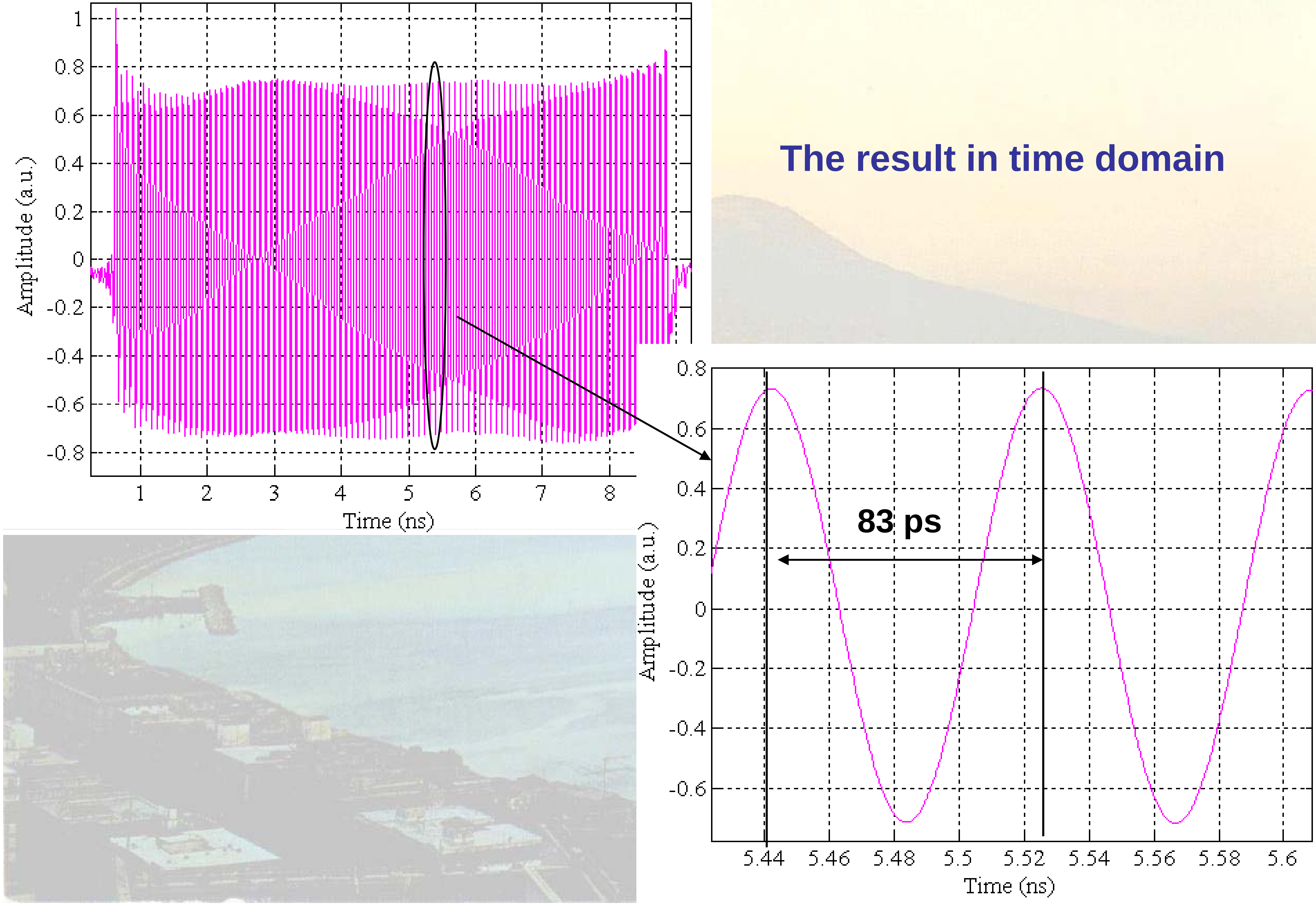




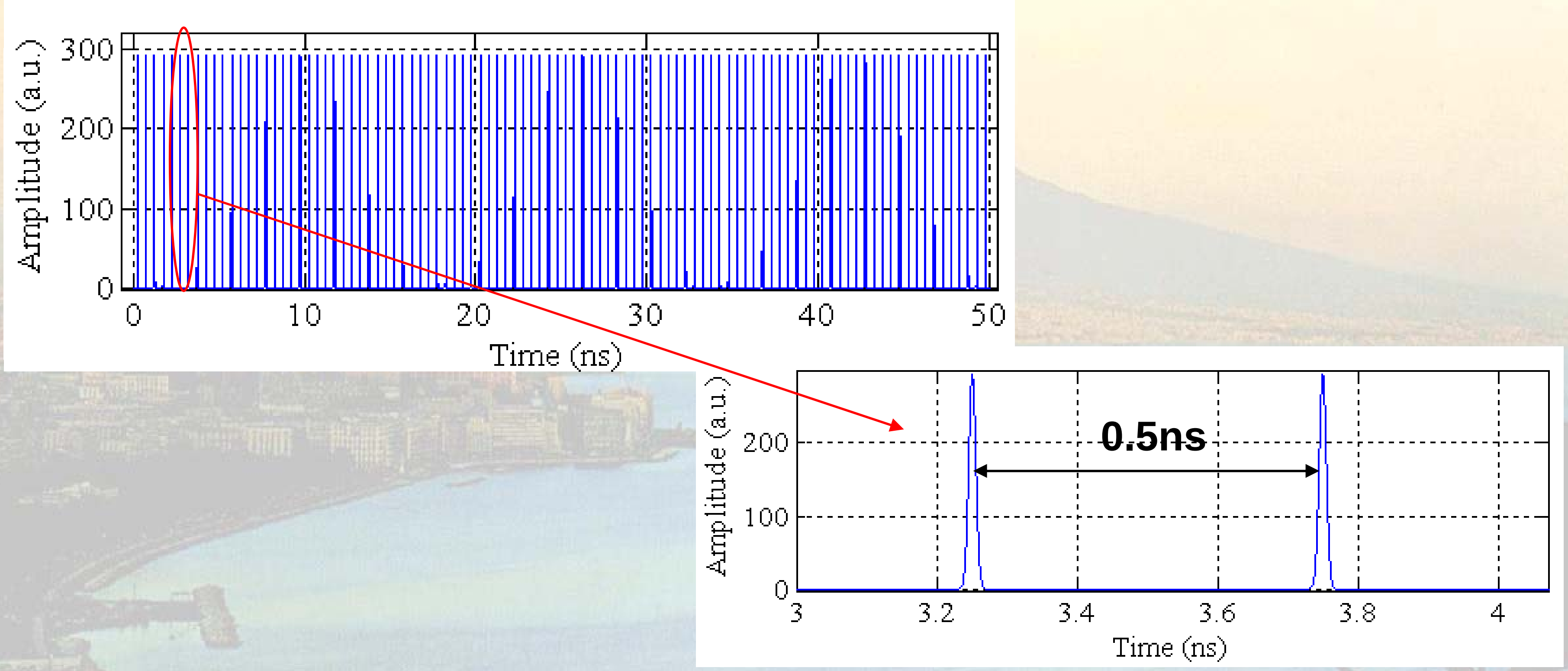
# Applying the WCM “real” signal

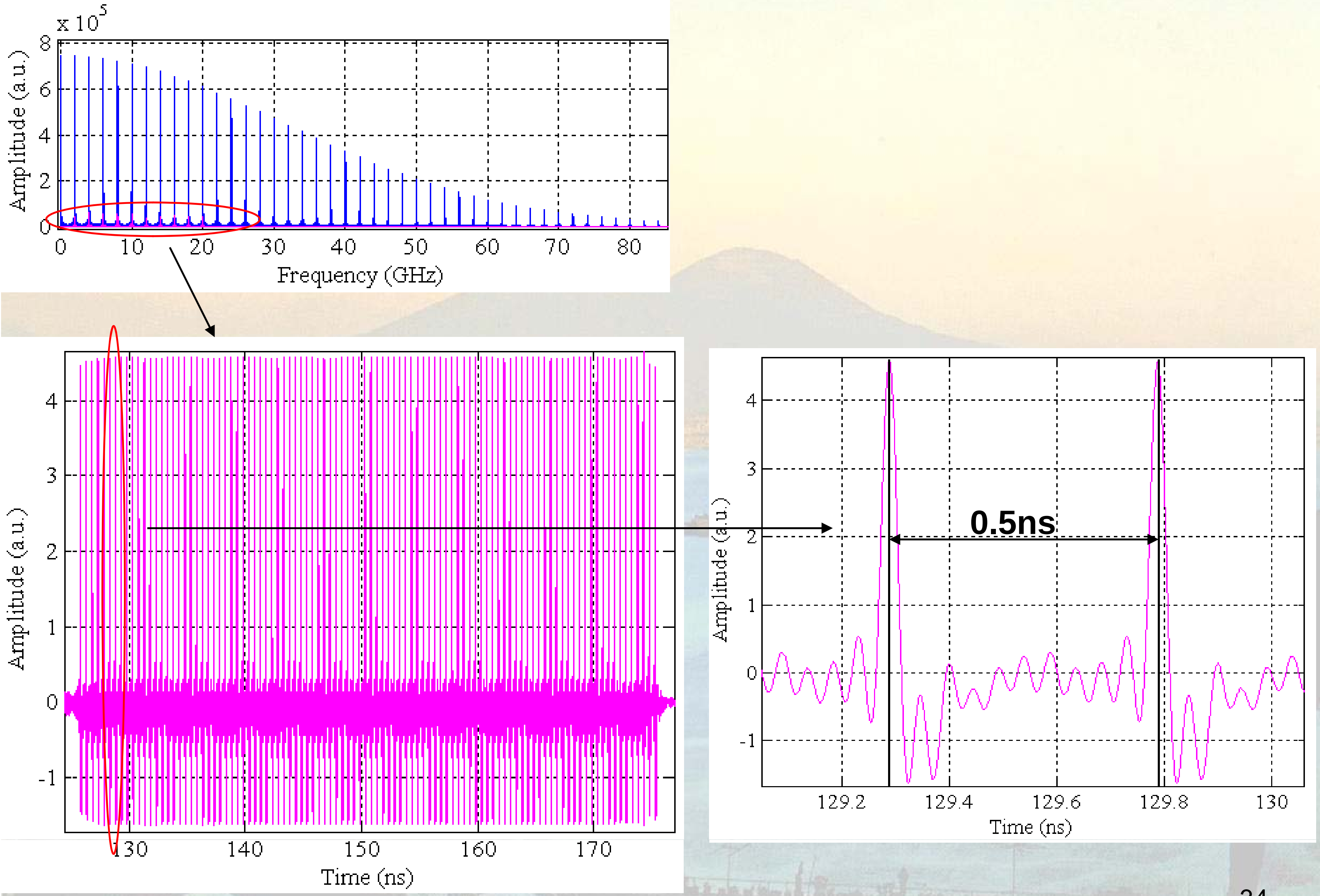


# The result in time domain

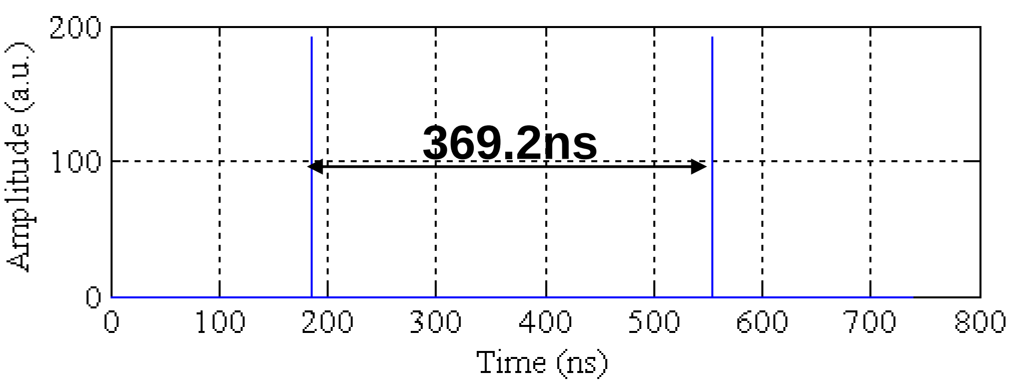


# WCM Signal Recovering: CLIC Main Beam

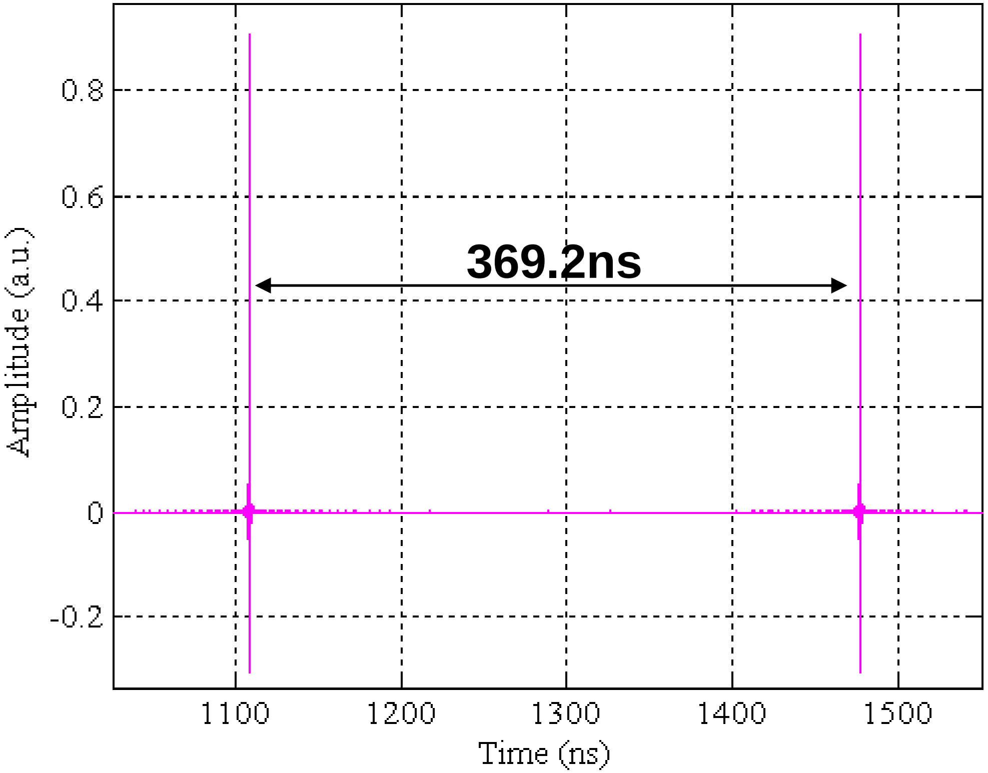



x 10^5
Amplitude (a.u.)
8
6
4
2
0
0
10
20
30
40
50
60
70
80
Frequency (GHz)
Amplitude (a.u.)
4
3
2
1
0
-1
130
140
150
160
170
Time (ns)
Amplitude (a.u.)
4
3
2
1
0
-1
129.2
129.4
129.6
129.8
130
Time (ns)
0.5ns

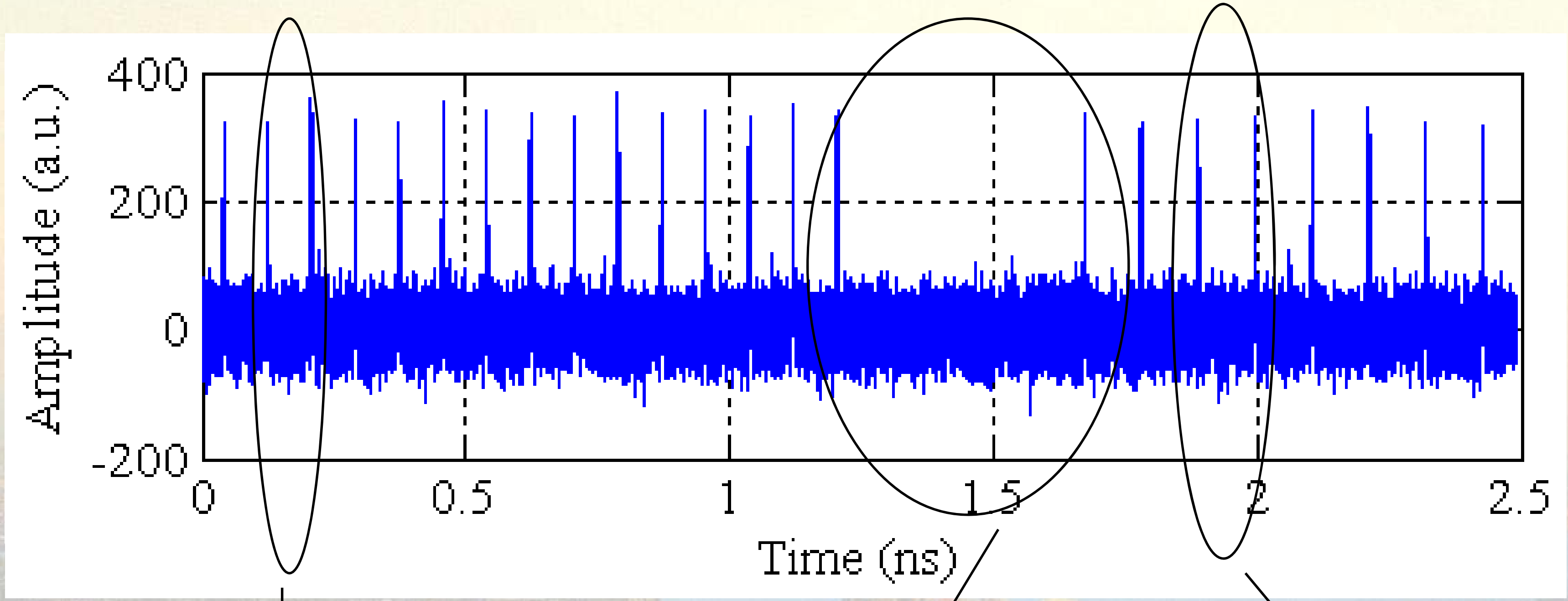
# WCM Signal Recovering: ILC Beam



## Recovering



# A last academic exercise



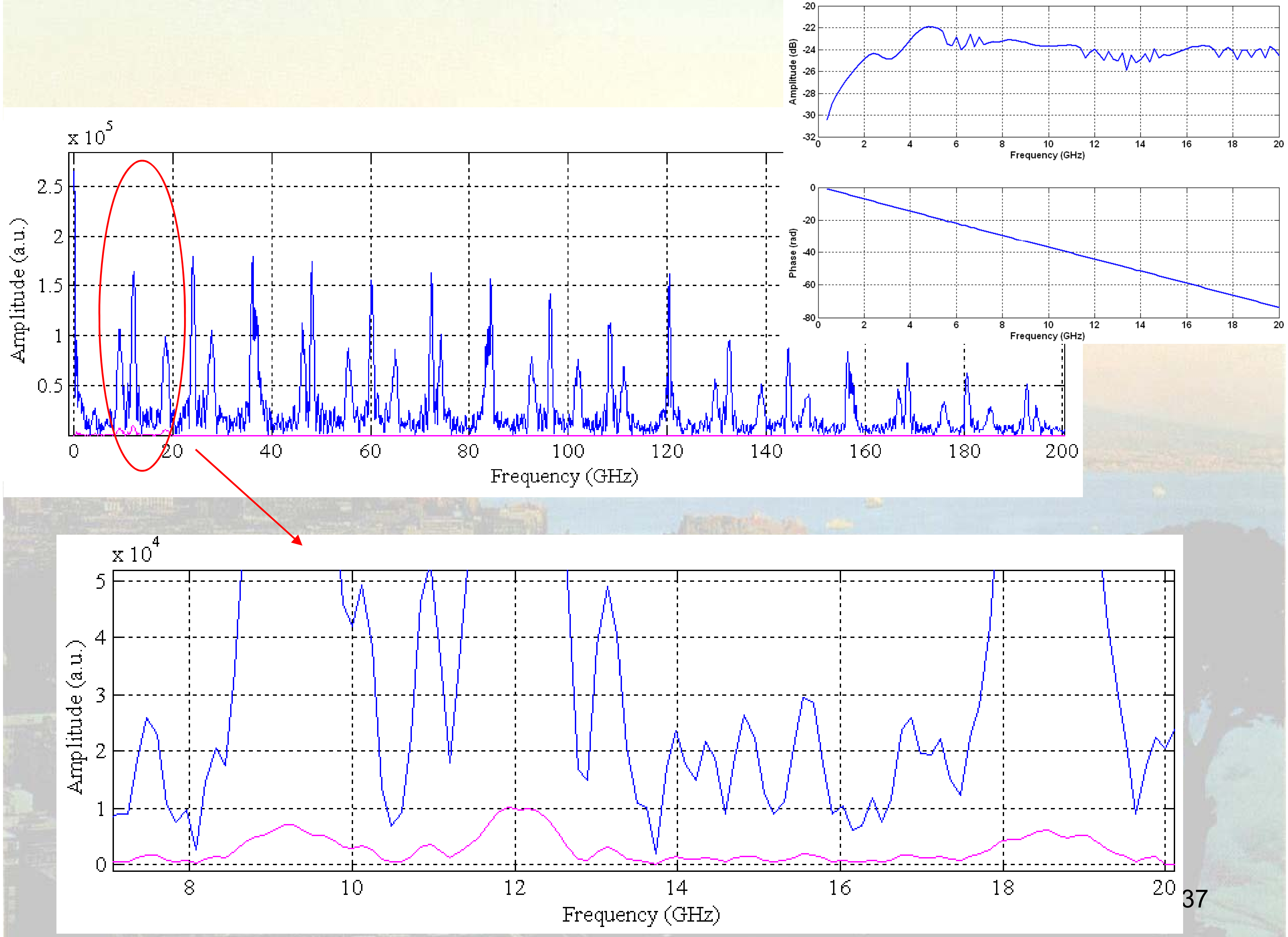
83 ps

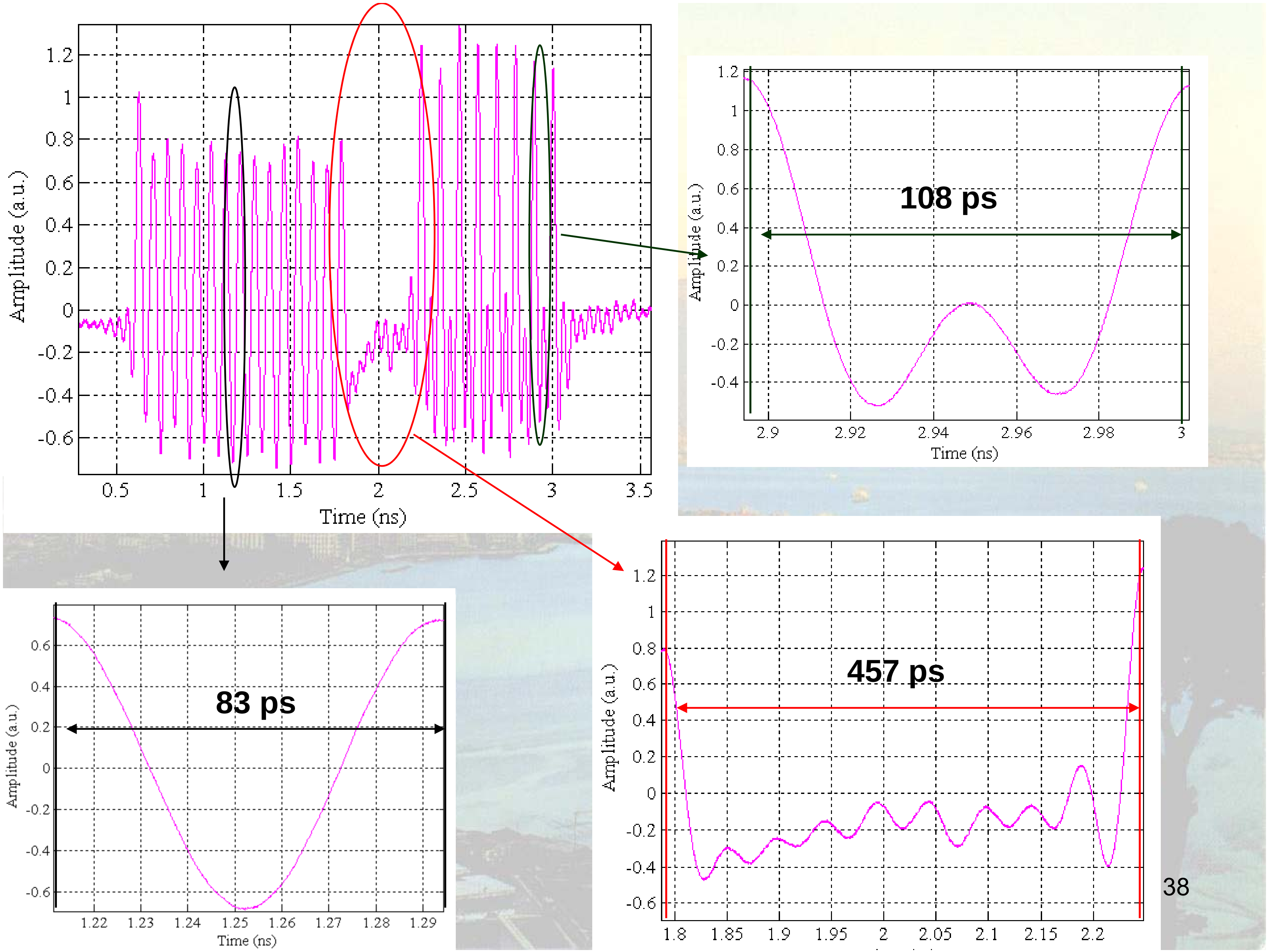
457 ps

108 ps

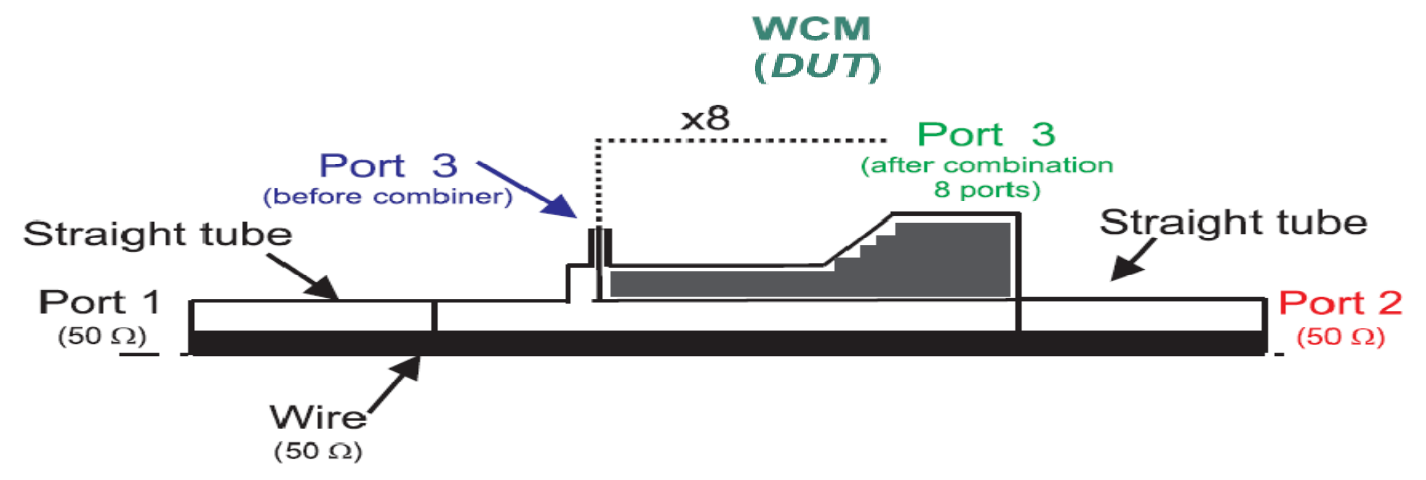
**RMS bunch length = 13.3ps**
**Train duration = 2.5ns**
**Nb of bunches = 23**
**Peak current = 293A**

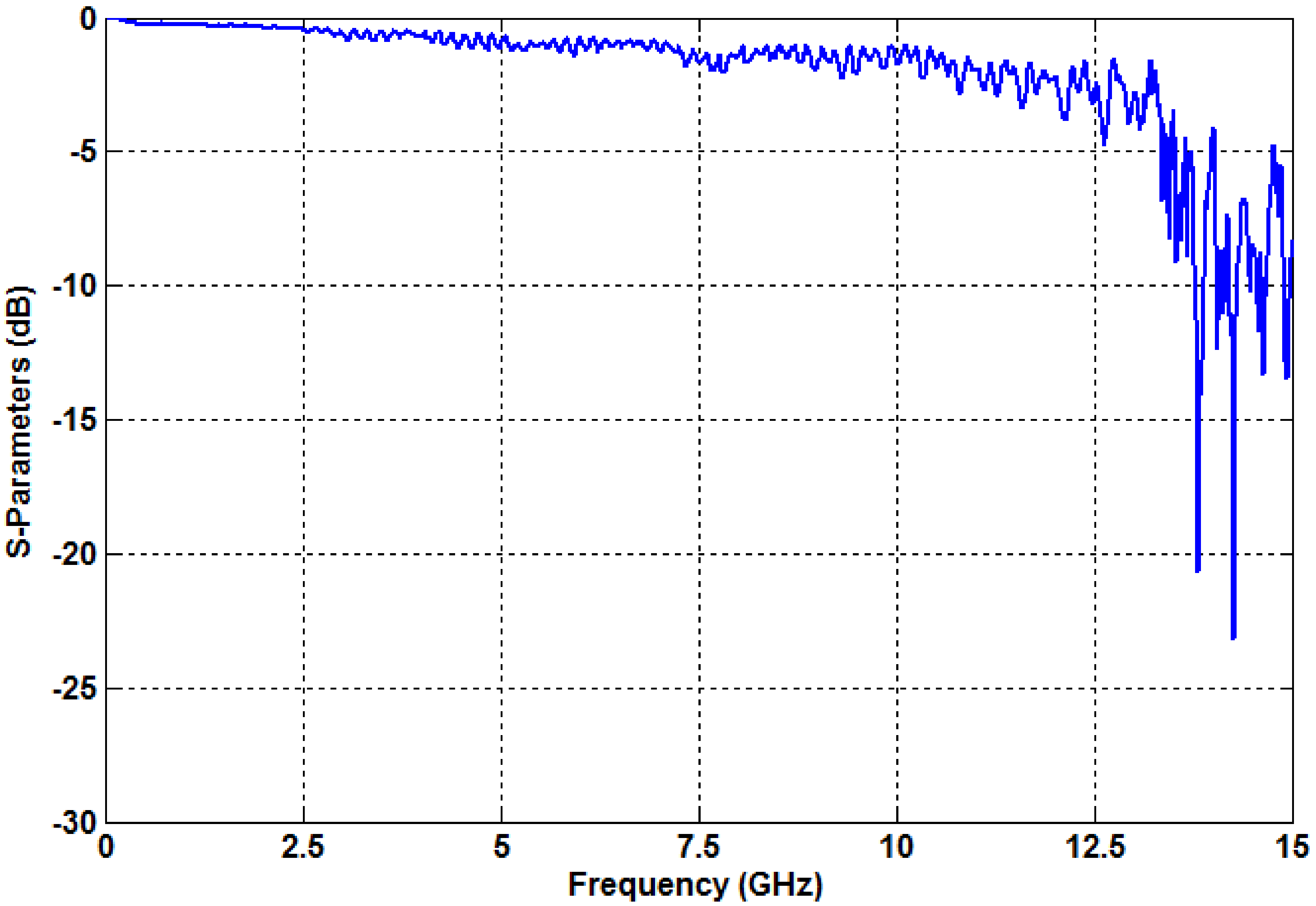
**Just to have more fun it has been added also a random noise level of about 10% with respect to the signal amplitude**

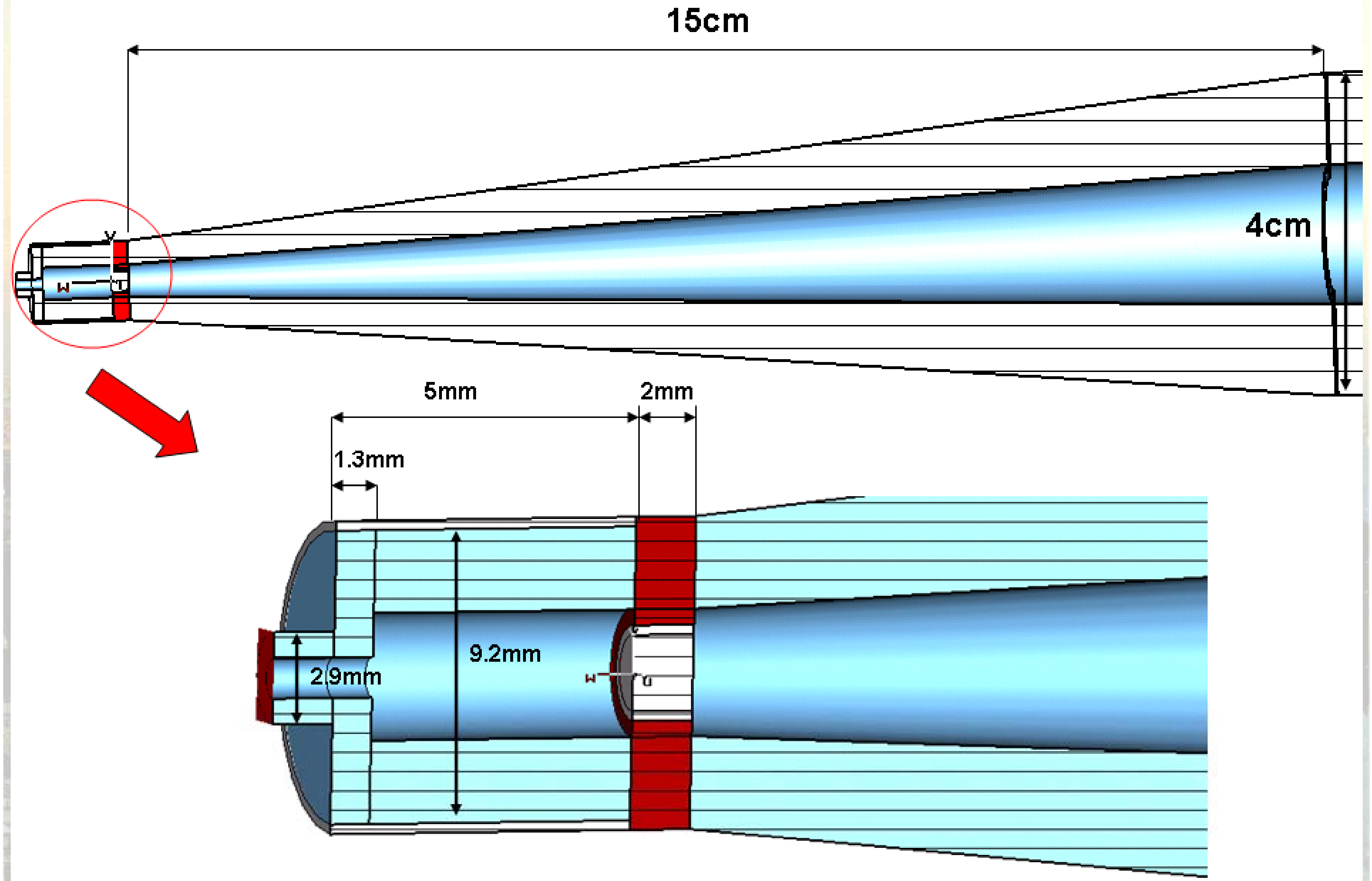

Amplitude (dB)
-20
-22
-24
-26
-28
-30
-32
0
2
4
6
8
10
12
14
16
18
20
Frequency (GHz)
Phase (rad)
0
-20
-40
-60
-80
Frequency (GHz)
x 10^5
Amplitude (a.u.)
2.5
2
1.5
1
0.5
0
20
40
60
80
100
120
140
160
180
200
Frequency (GHz)
x 10^4
Amplitude (a.u.)
5
4
3
2
1
0
8
10
12
14
16
18
20
Frequency (GHz)


Amplitude (a.u.)
Time (ns)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.5
1
1.5
2
2.5
3
3.5
108 ps
2.9
2.92
2.94
2.96
2.98
3
83 ps
1.22
1.23
1.24
1.25
1.26
1.27
1.28
1.29
457 ps
1.8
1.85
1.9
1.95
2
2.05
2.1
2.15
2.2

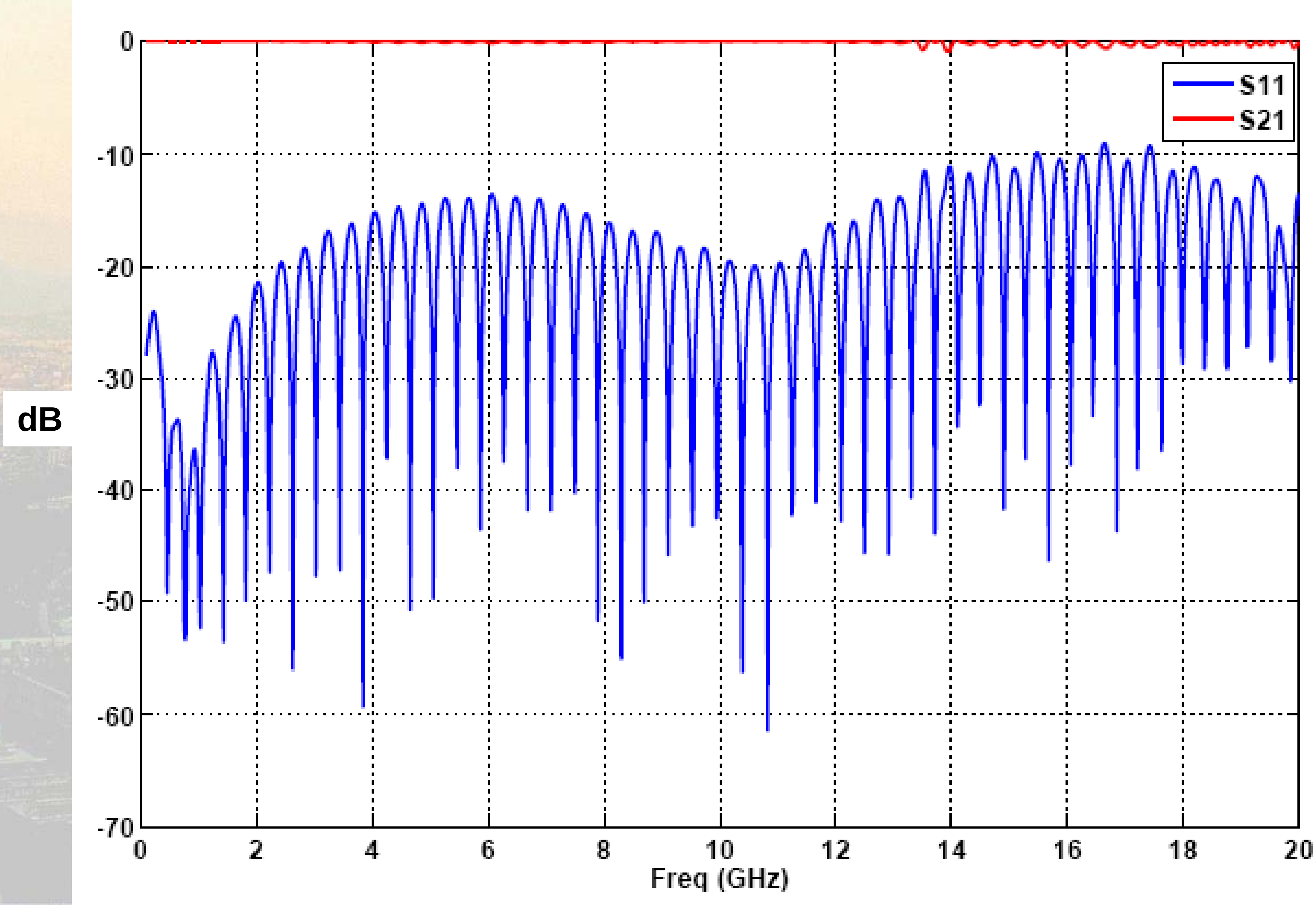
# Experimental setup and testbench



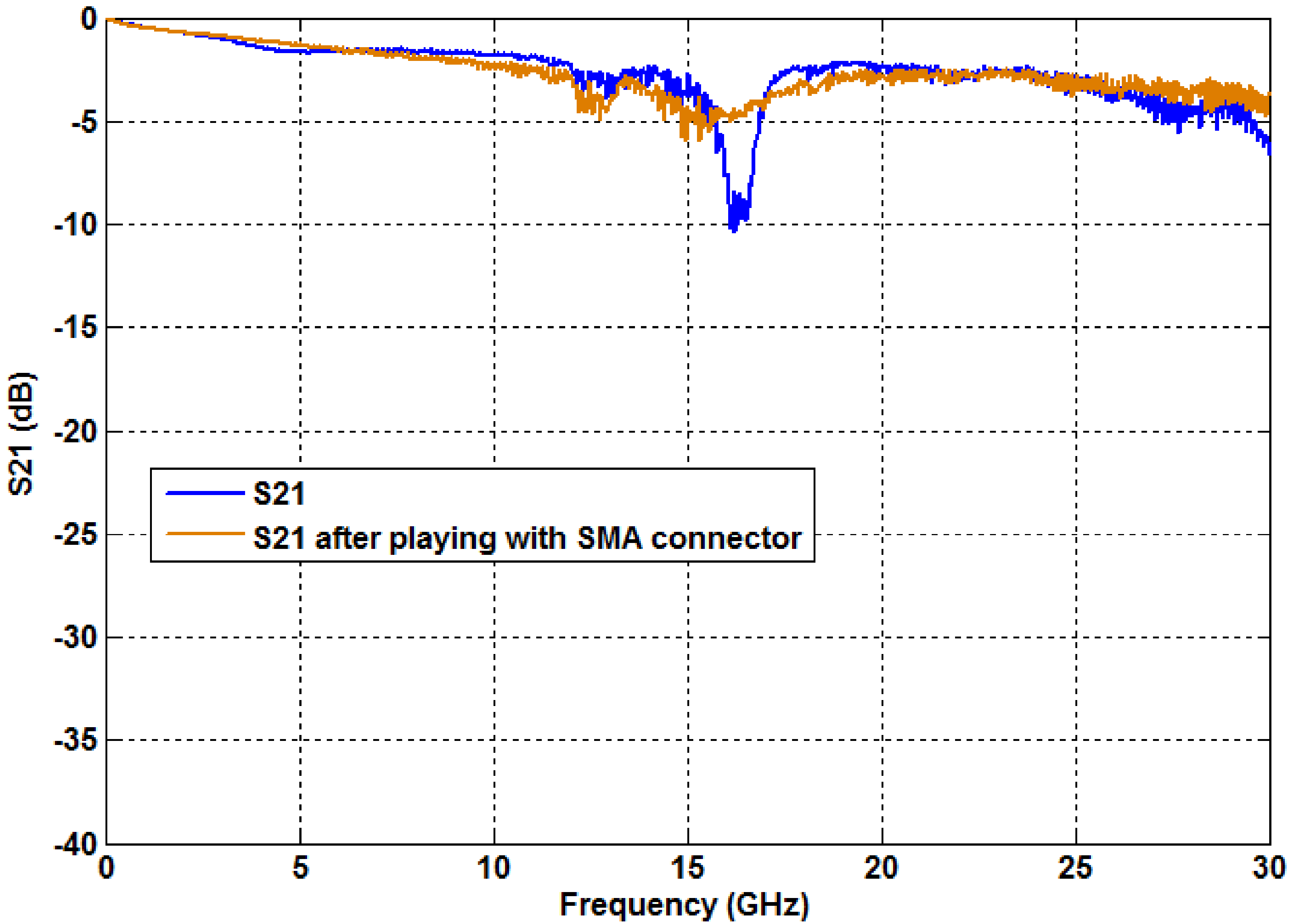

0
-5
-10
-15
-20
-25
-30
S-Parameters (dB)
0
2.5
5
7.5
10
12.5
15
Frequency (GHz)

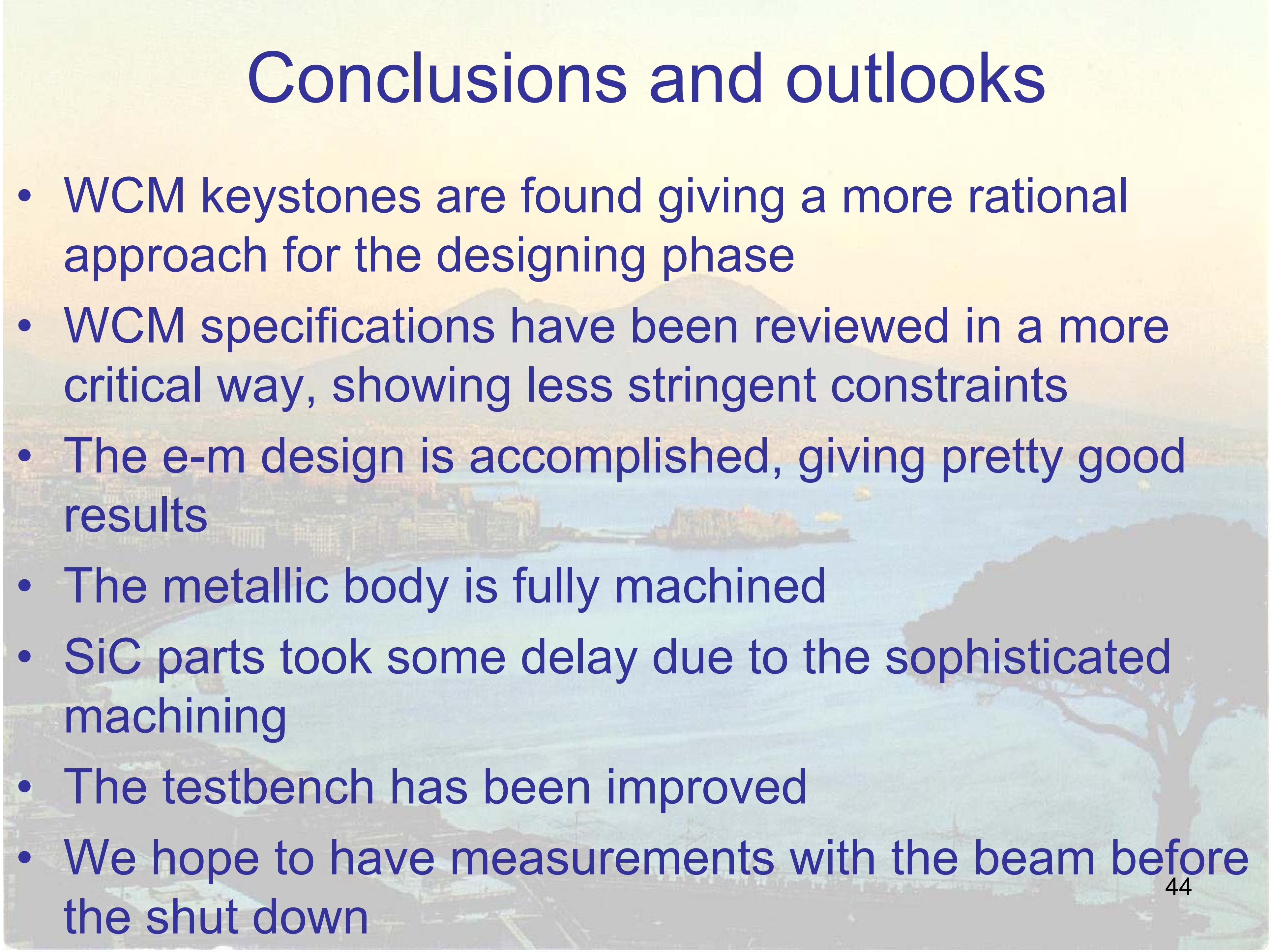

15cm
4cm
5mm
2mm
1.3mm
9.2mm
2.9mm

# Simulation



# Measurement





# Conclusions and outlooks

- WCM keystones are found giving a more rational approach for the designing phase
- WCM specifications have been reviewed in a more critical way, showing less stringent constraints
- The e-m design is accomplished, giving pretty good results
- The metallic body is fully machined
- SiC parts took some delay due to the sophisticated machining
- The testbench has been improved
- We hope to have measurements with the beam before the shut down