CAS Erice 2013

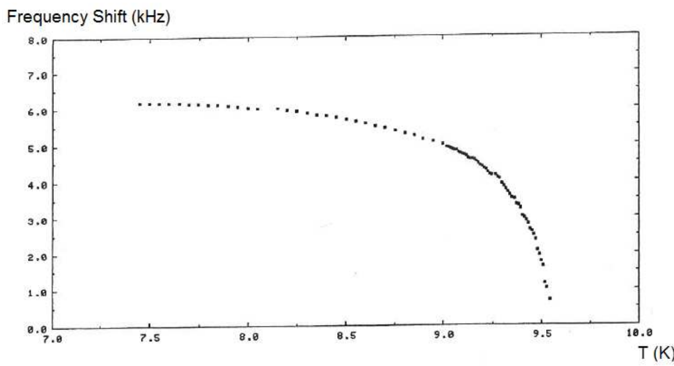
# Case Study

## RF cavities: superconductivity and thin films, local defects…

### Thin Film Niobium

Due to bulk niobium costs, for moderate field applications it is sometime less expensive to deposit a thin layer of Niobium onto a copper cavity. It is often the case for cavities dedicated to circular machine where high gradients are not mandatory.

- For the first part of the problem we will deal with a 1.3 GHz cavity with a geometric factor G= 270. The resonance frequency of the cavity is monitored at small RF field during the cool down procedure. A frequency shift is observed as shown in Figure 1.



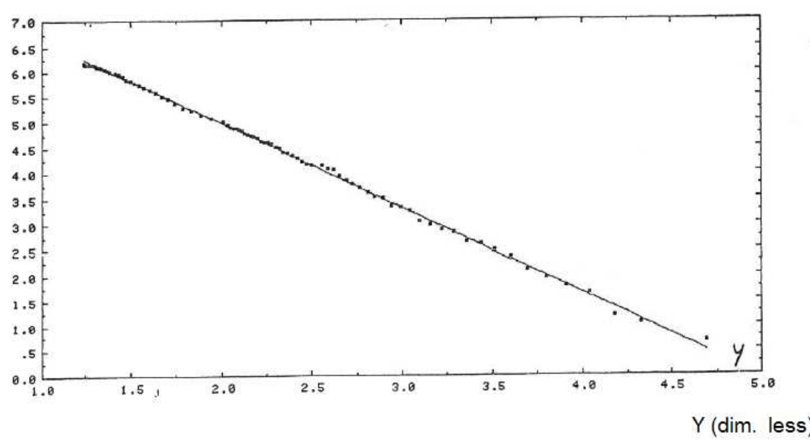




Figure 1 Frequency shift during cooldown. Linear representation is given in function of Y, where $Y = (1-(T/T_C)^4)^{-1/2}$

Q1 : What can explain the variation of frequency observed ?

Q2 : Calculate the penetration depths of the film. Make the comparison with bulk value. How can you explain the difference?

The calculation can be done considering the frequency variation within the perturbation limit with the Slater formula:

$$\frac{\Delta F}{F_0} = \frac{\pi \mu_0 \ F_0}{G} \Delta\lambda$$

where $\lambda$ figures the penetration depth in the Pippard limit.

- Figure 2 shows the RF test of cavity of Nb deposited onto Cu. A “hot spot” is detected precisely at the equator (Z=0). It is attributed to a portion of the film with poor adherence (considered like a disk with surface << of the cavity surface for simplicity)

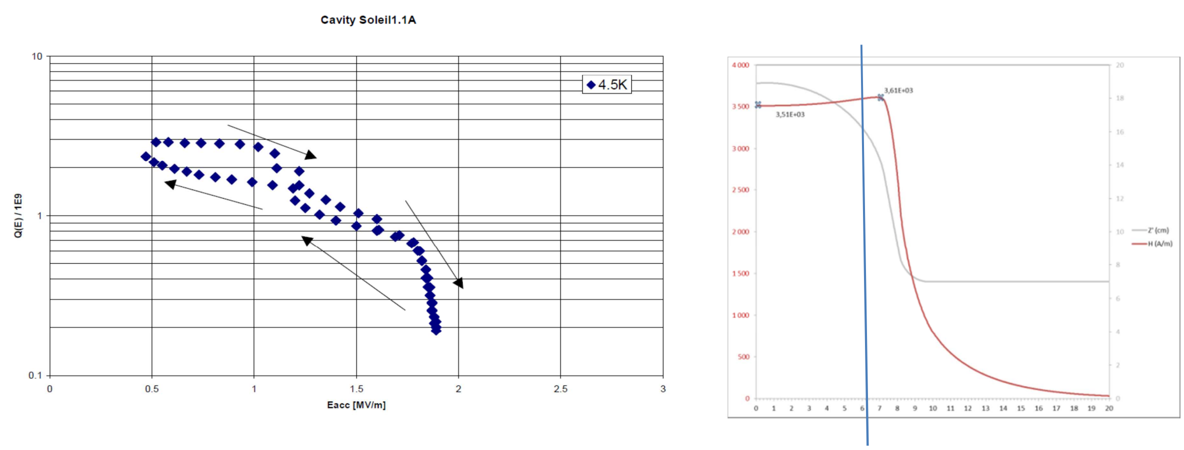



**Figure 2 left RF test of at 4.5 K of a Nb film cavity, right typical field distribution in an elliptical cavity**

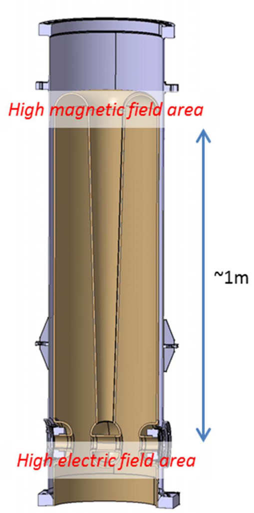
Q3 : explain qualitatively the experimental observations.

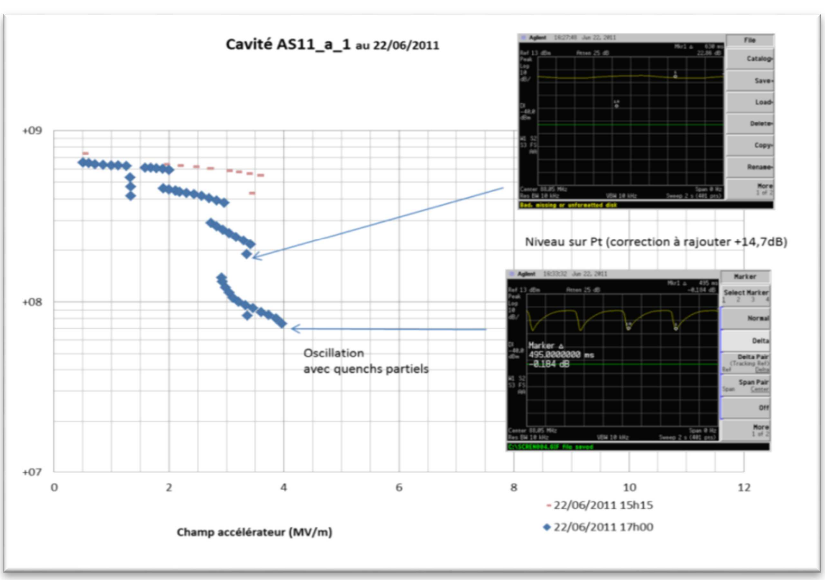
Q4 : deduce the surface of the defect. (For simplicity, one will take the field repartition and dimension from the ESS cavity shown on the right. Note the the actual field $B_{peak}$ is proportional to $E_{acc}$ ($B_{pea\sim}$42Oe/MV/m)x Eacc). G = 270W and Rs in normal state = 2m$\Omega$

Q5: If the hot spot had been observed 7.3 cm from the equator, what conclusion could you draw from the experimental data ?

## Dissipation in bulk Nb

Q-switches can also be observed in bulk Nb cavities



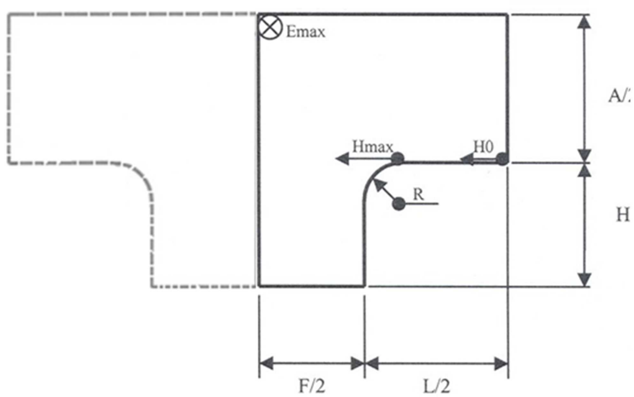

Q6 : regarding the previous questions, and the field distribution in these cavities, how can you explain the multiple observed Q-switches ?

## Modeling of a step @ grain boundary

### EM model

We will start with a very simple model, where we consider a half electromagnetic cell as shown below:

R is the curvature radius of the defect, and L and H represent respectively the width and height of the step.




The calculation of the field enhancement for such a system can be fitted with:

$$H\max/H0 = 1 + 0.59 \times \left(\frac{H}{R}\right)^{0.5}$$

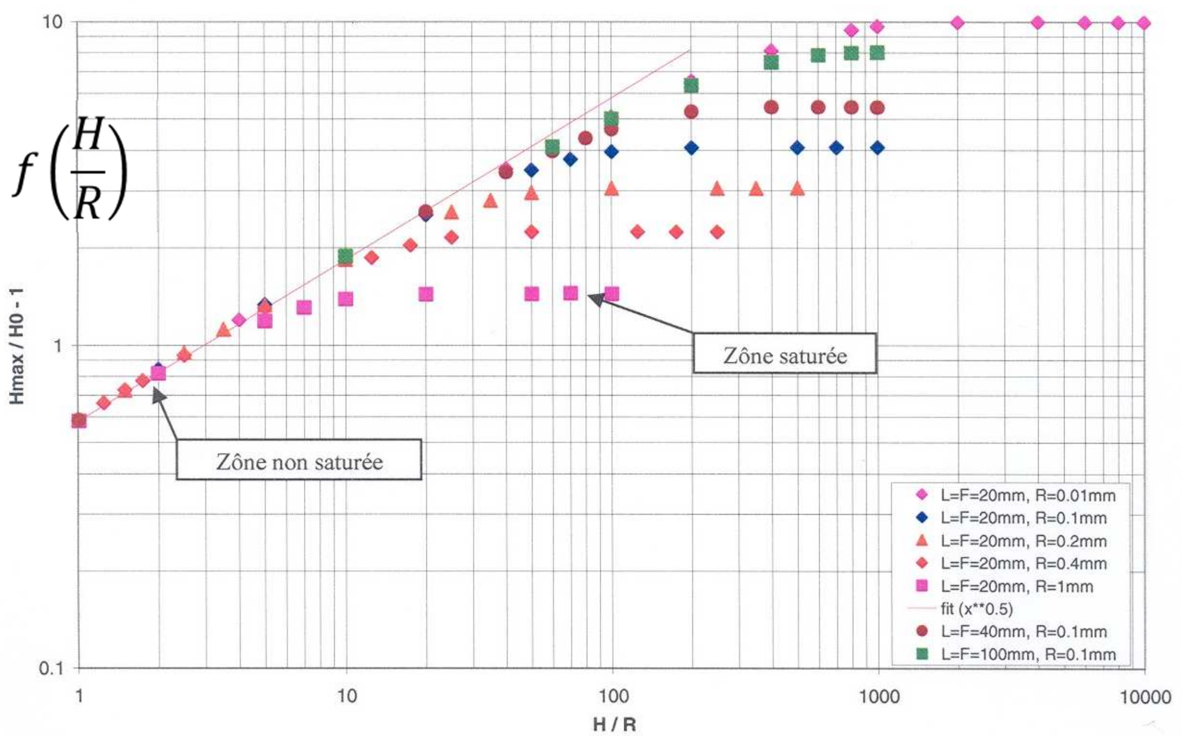
$$0.1 \le \frac{F}{L} \le 10$$

$$H\max/H0 = 1 + 0.266 \times \left(\frac{F}{L}\right)^{0.3} \times \left(\frac{F+L}{R}\right)^{0.45}$$

$$0.2 \le \frac{F}{L} \le 5$$

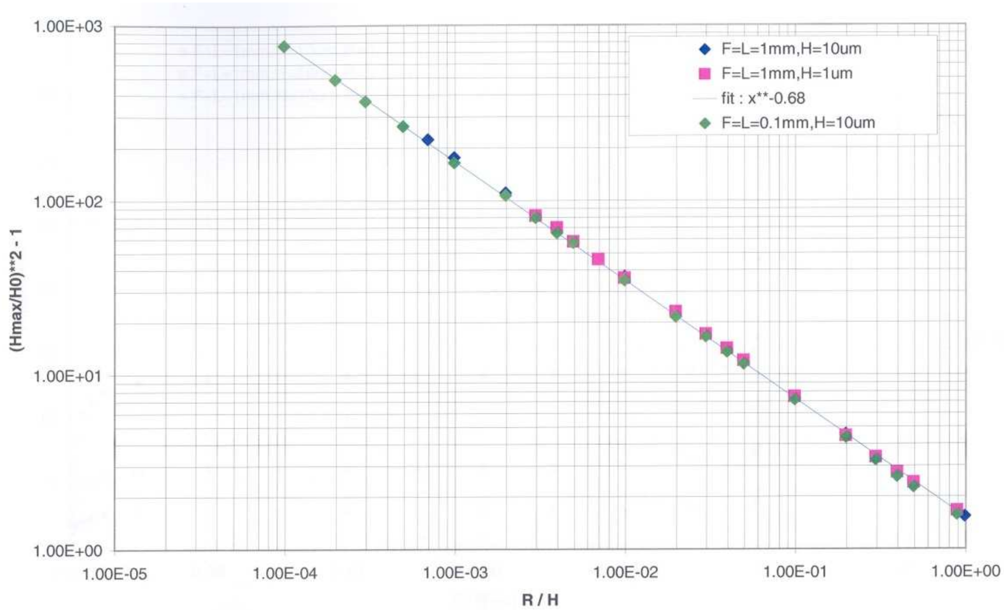
Results are showed in the following figures:

$$\frac{H_{max}}{H} - 1 = f\left(\frac{H}{R}\right)$$



$$\left(\frac{H_{max}}{H}\right)^2 - 1 = f\left(\frac{H}{R}\right)$$

In the saturation region




**Q7.** What conclusion can we draw about

The influence of the lateral dimensions of the defect? Its height ?

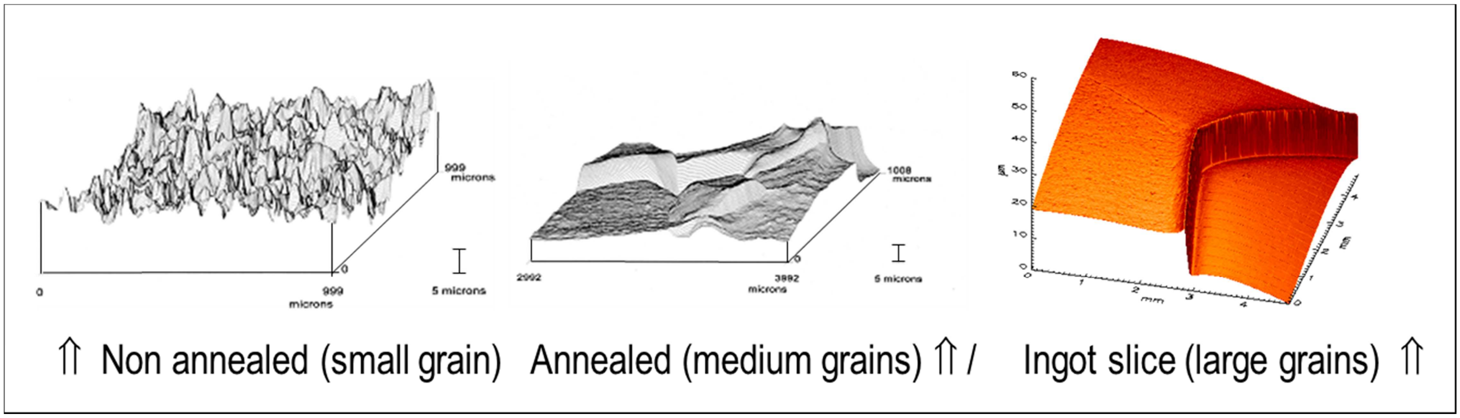
The influence of the curvature radius?

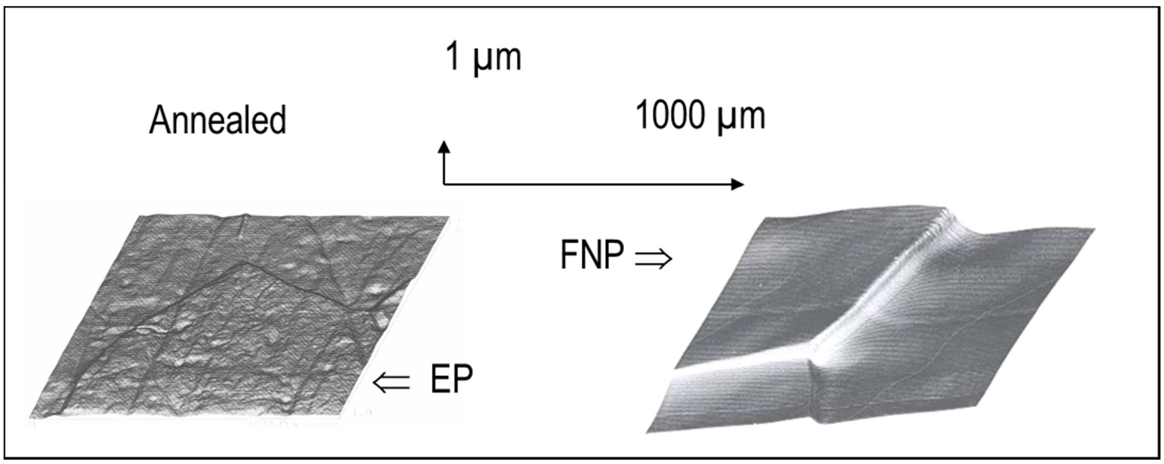
The behavior at high field?

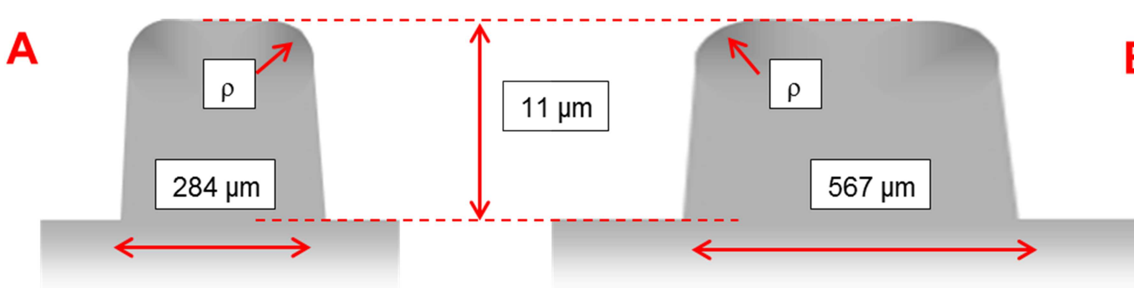
What happens if the defect is a hole instead of bump (F<<L) ?

## Grains with realistic dimension

The following pictures show profilometry measurements of various niobium surface states (extended z-axis). Chemically etched niobium exhibit steps that look pronounced in this scale, but have in reality very large curvature angles (some 100eds µm). We will see that even “smooth” steps” can play an important role in the apparition of the breakdown




2-D EM only calculations. Green curve show the power evolution in a cavity without the grain contribution. Blue curve show the grain only contribution, supposing regions with H<H have a normal conducting surface resitance (2 mW).

<table>
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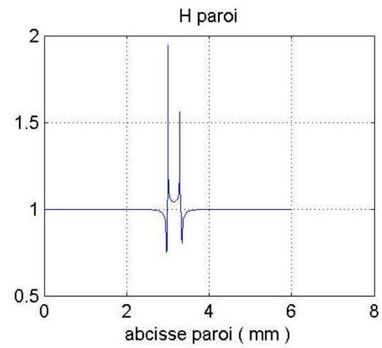
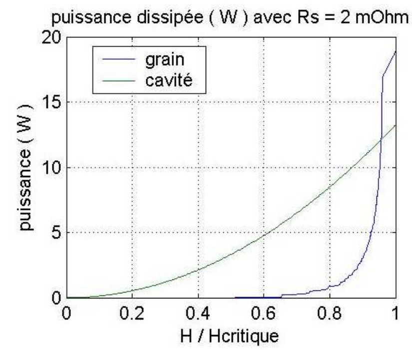
<tr><td>1</td><td>
</td><td>
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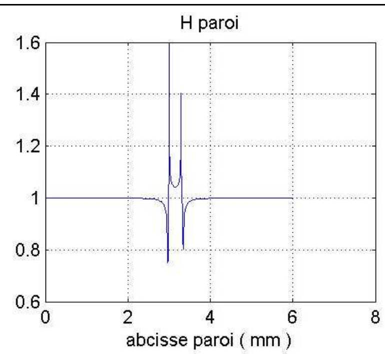
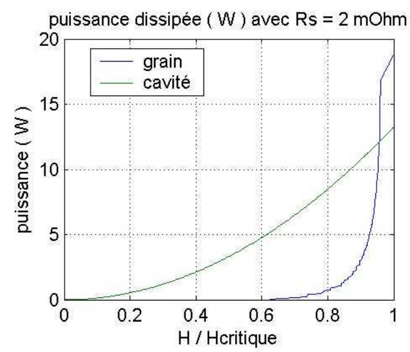
<tr><td>6</td><td>
</td><td>
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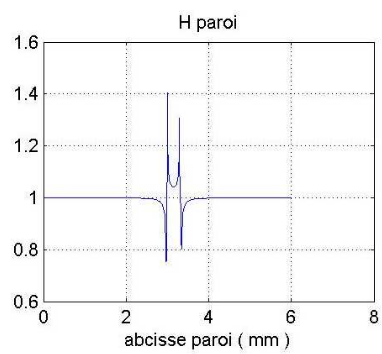
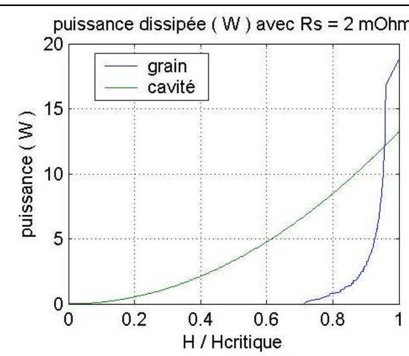
<tr><td>20</td><td>
</td><td>
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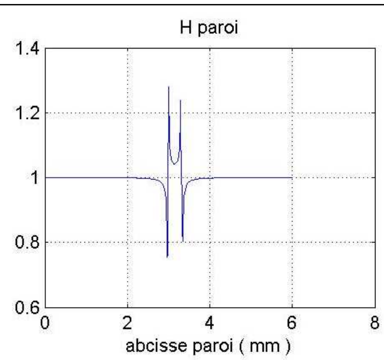
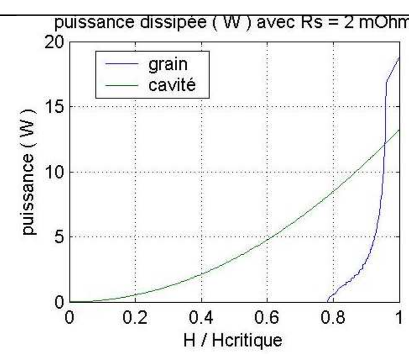
<tr><td>50</td><td>
</td><td>
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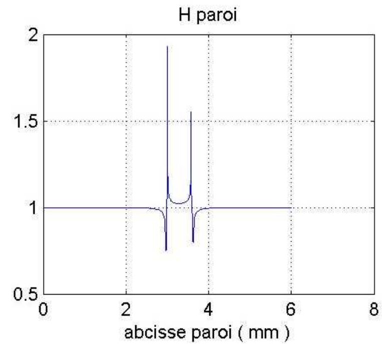
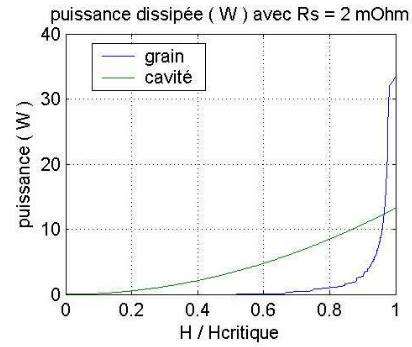
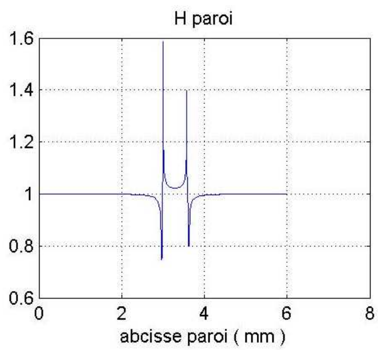
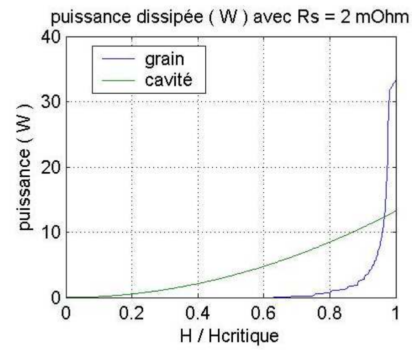
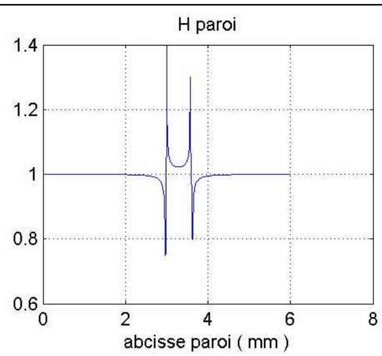
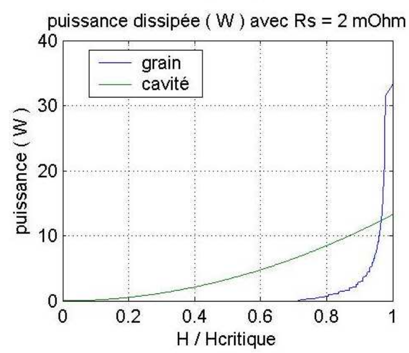
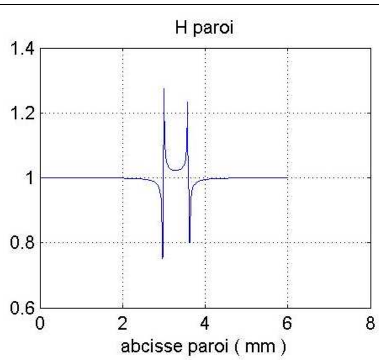
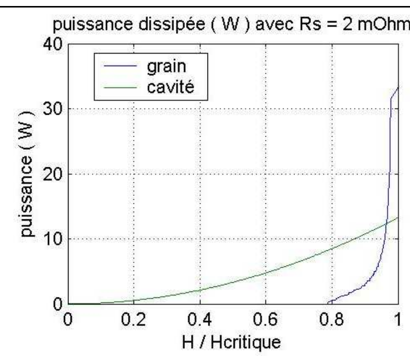
| B | | |
|---|---|---|
| r | Local field | Dissipated power : local/mean value |
| 1 |  |  |
| 6 |  |  |
| 20 |  |  |
| 50 |  |  |

**Q8.-** do these calculation change the conclusion from the precedent simplified model ?

- what prediction can be done about the thermal breakdown of the cavity?

-Why is this model underestimating the field enhancement factor and overestimating the thermal dissipations?

## Thermal + RF model

Here below we will consider the influence of thermal parameters to the cavity stability in the presence of a morphologic defect, specifically the interface exchange limitation (Kapitza resistance).

The following assumptions were made:

Material: Nb with $T_C$ = 9.2 K, thermal conductivity = 54W/m/K (n reality $\kappa$ varies strongly with T)

$B_{C1}$ ~200 mT and $B_{C2}$ = 2 $B_{C1}$

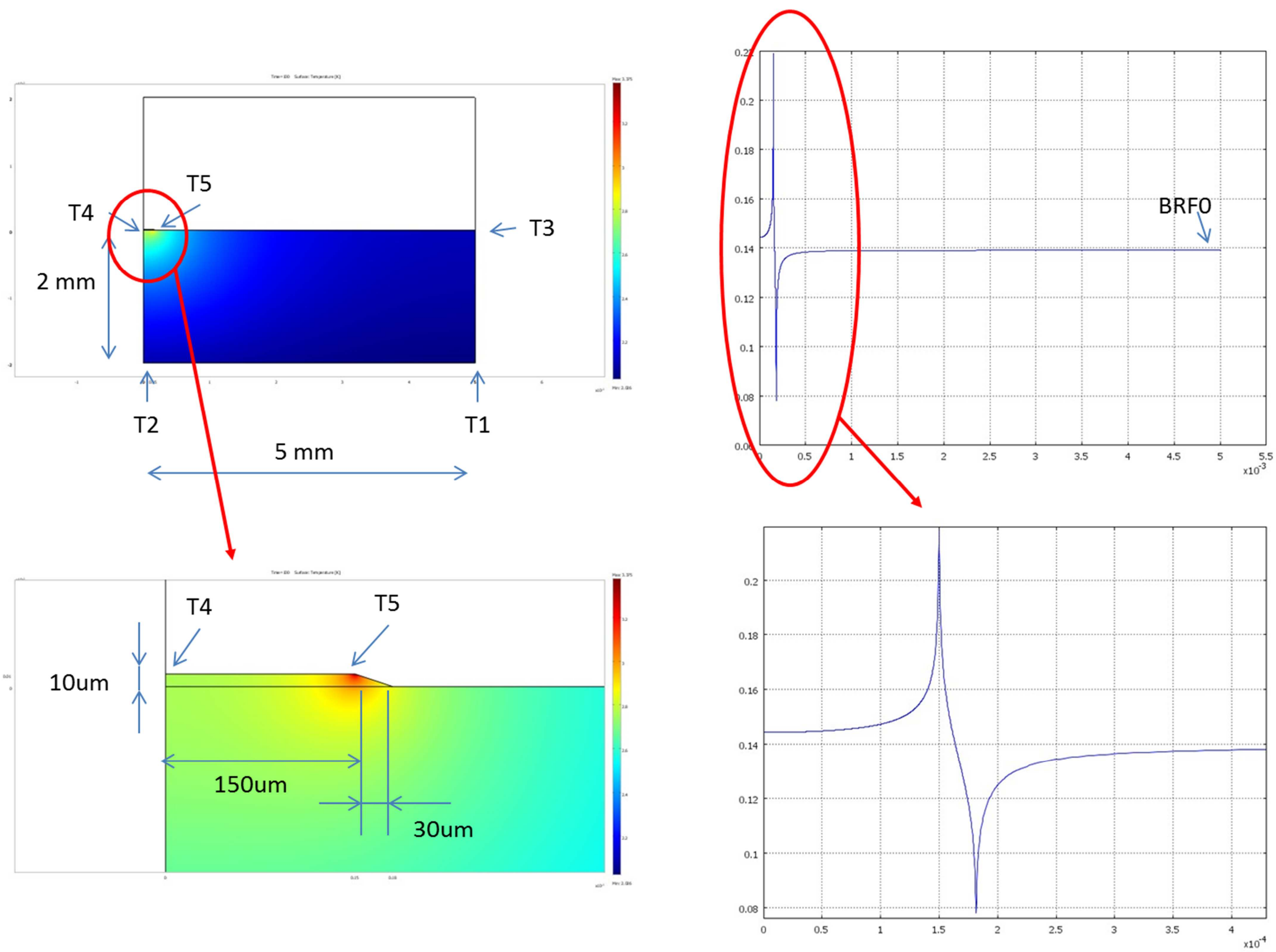
$R_S$

in superconducting state = 200n$\Omega$ (overestimated)

in normal state = 2m$\Omega$ (linear variation inbetween)

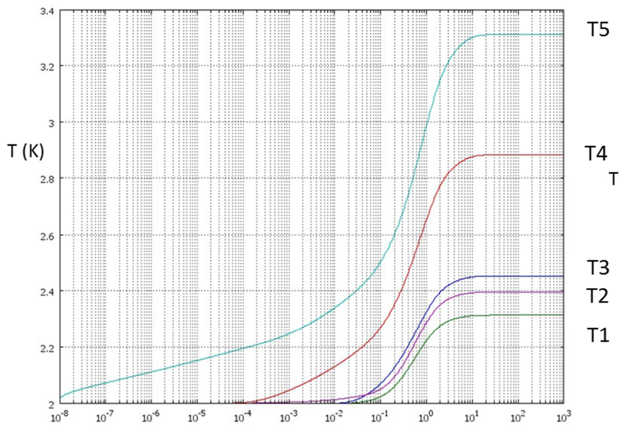
BRF0 corresponds to the applied RF field in absence of defect.

We are still dealing with a 2D model (1/Rk in W/m/K instead of W/m2/K)




The power evacuated to the helium bathe (when the situation is stable) is indicated below the left curve (below)

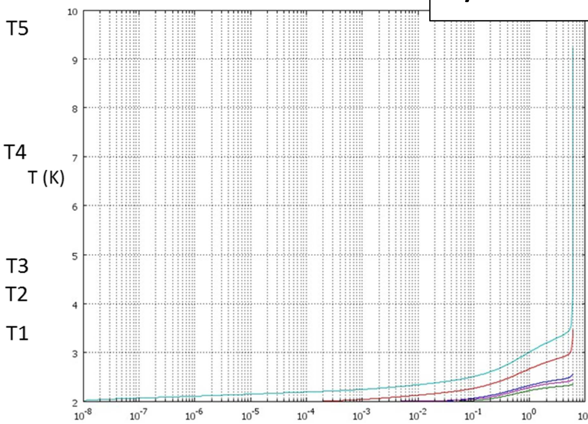
BRF0 = 0.1390 T




Time (s) P = 18.59 W

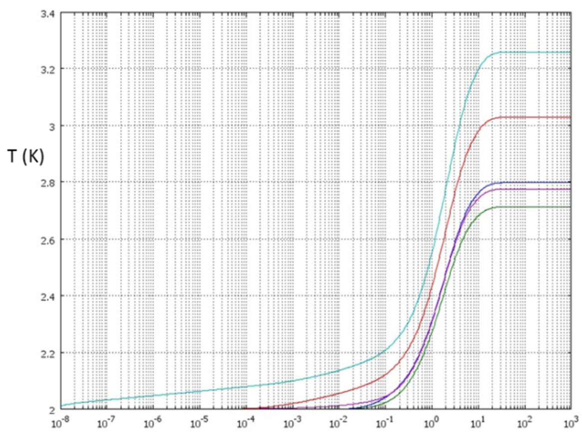
BRF0 = 0.1391 T

**1/Rk 10 000 W/m/K**




Time (s)

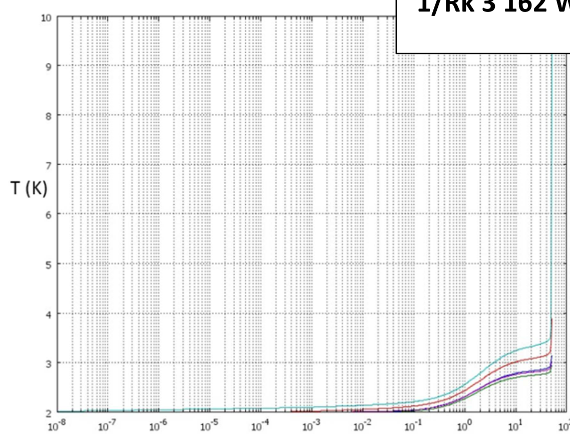
BRF0 = 0.1323 T




Time (s) P = 11.83 W

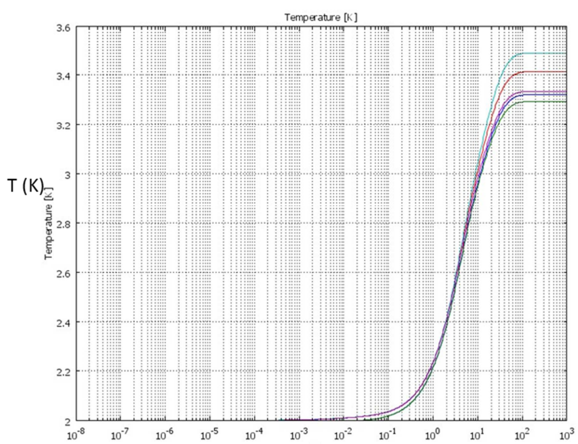
BRF0 = 0.1324 T

**1/Rk 3 162 W/m/K**




Time (s)

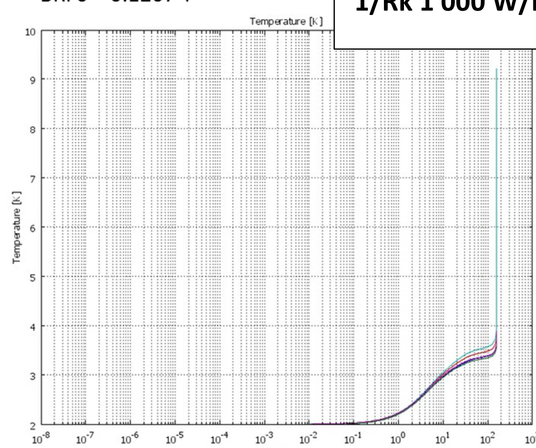
BRF0 = 0.1206 T




Time (s) P = 6.53 W

BRF0 = 0.1207 T

**1/Rk 1 000 W/m/K**




Time (s)

**Q9** Comment these figures. What will happen if we introduce thermal variation of $\kappa$, and/or $R_S$. What happen if we increase the purity of Nb ?