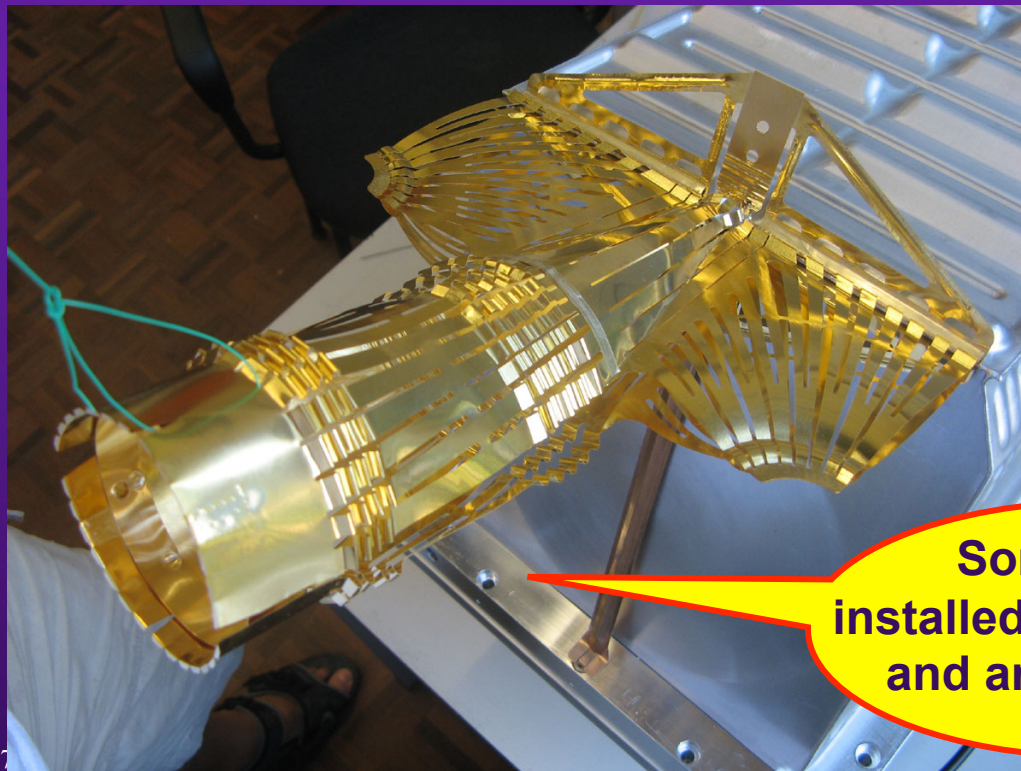


# OUTCOMES OF THE LRFF (LHC RF FINGERS) TASK FORCE IN 2012

**E. Métral, O. Aberle, R.W. Assmann, V. Baglin, M.J. Barnes, O.E. Berrig, A. Bertarelli, G. Bregliozzi, S. Calatroni, F. Carra, F. Caspers, H.A. Day, M. Ferro-Luzzi, M.A. Gallilee, C. Garion, M. Garlasche, A. Grudiev, J.M. Jimenez, R. Jones, O. Kononenko, R. Losito, J.L. Nougaret, V. Parma, S. Redaelli, B. Salvant, P. Strubin, R. Veness, C. Vollinger, W. Weterings**



# OUTLINE (1/2)

- ◆ **Introduction**
- ◆ **Why do we need RF fingers and/or ferrite (absorbers)?**
- ◆ **What we planned to do**
- ◆ **What was done**
- ◆ **RF fingers**
  - **Several designs**
  - **Possible issues to consider**
  - **Example of a known issue with a TCDD**
  - **Typical nonconformities found with X-rays**
  - **List of all the nonconformities**
  - **Recent issues observed with RF contacts in SPS**
  - **Guidelines**

## OUTLINE (2/2)

- ◆ **Ferrite absorbers**
  - Several types, criteria and guidelines
  - Measurements of the EM properties
  - Figure of merit and design guidelines for the ferrite heating
  - Measurements of the vacuum properties
- ◆ **Pros and cons of RF fingers and ferrite absorbers**
- ◆ **What was wrong with the PIMs in the cold part of LHC?**
- ◆ **Follow-up of VMTSA issues in 2011**
- ◆ **Conclusions and recommendations**

# INTRODUCTION (1/3)

- ◆ Beam-induced heating has been observed in several LHC components during the 2011 run when the bunch/beam intensity was increased and/or the bunch length reduced
- ◆ In particular 8 bellows, out of the 10 double-bellows modules (called VMTSA) present in the machine, were found with the spring, which should keep the RF fingers in good electrical contact with the central insert, broken
- ◆ SS spring deformed and brazed to the CuBe RF fingers with RF fingers permanently deformed => Estimated temp. of  $\sim 800 - 1000 \text{ }^\circ\text{C}$

From X-rays

Typical default, DCUM 3259.3524

Left side

Vincent Baglin (LMC, 16/11/11)

Side view (xray from corridor to QRL)

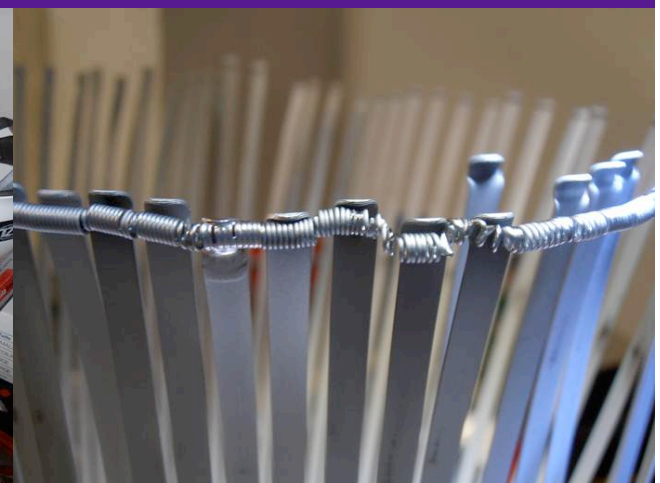
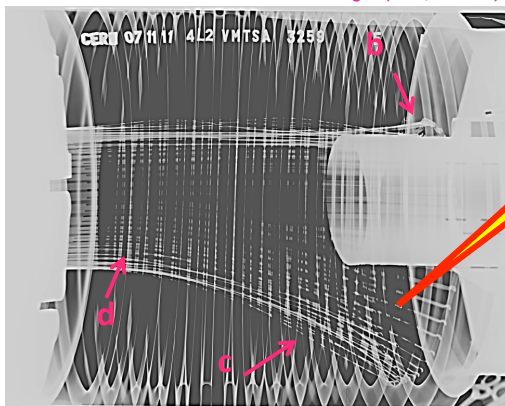
b) Metallic noise due to loose spring when hitting vacuum chamber

c) RF fingers falling due to broken spring

d) aperture reduced ?

Non Conform

Spring was broken between May and November 2011



# INTRODUCTION (2/3)

- ◆ Proposition made during the LMC meeting # 119 (18/01/2012) to review the design of all the components of the LHC equipped with RF fingers => LRFF (LHC RF Fingers) Task Force before LS1
- ◆ Web site: <http://emetral.web.cern.ch/emetral/LRFF/LRFF.htm>
  - 1<sup>st</sup> (kick-off) meeting: 20/03/2012
  - 20<sup>th</sup> (last) meeting: 27/11/2012
- ◆ Members

- [Elias Metral](#) (chairman, BE/ABP).

- [Jose Miguel Jimenez](#) (alternate, TE/VSC) => Could be replaced by [Sergio Calatroni](#).

- For TE/VSC (Vacuum, Surfaces and Coatings): [Vincent Baglin](#) and [Giuseppe Bregliozzi](#) (alternate).

- For EN/STI (Sources, Targets & Interactions): [Oliver Aberle](#) and [Roberto Losito](#).

- For TE/ABT (Accelerator Beam Transfer): [Wim Weterings](#) (mechanical issues) and [Mike Barnes](#) (impedance-related aspects).

- For BE/RF (Radio Frequency): [Fritz Caspers](#), [Alexej Grudiev](#) and [Oleksiy Kononenko](#).

- For BE/BI (Beam Instrumentation): [Rhodri Jones](#) and [Raymond Veness](#) (alternate).

- For BE/ABP (Accelerators and Beam Physics): [Benoit Salvant](#), [Hugo Day](#) and [Olav Berrig](#) (EM simulations and wire measurements), [Ralph Assmann](#) (task leader of the "Intensity limitations in the LHC" task within WP2 of the HL-LHC project) and [Stefano Redaelli](#) (LHC Collimation project leader).

- For EN/MME (Mechanical & Materials Engineering): [Alessandro Bertarelli](#) and [Marco Garlasche](#).

- For TE/MSC (Magnets, Superconductors and Cryostats): [Vittorio Parma](#).

- Others?

- Someone from the Design Office (i.e. designer of a particular equipment) might be needed at some point => Alessandro Bertarelli will be the link person.
- Someone from Cryo could be invited at some point (after the first recommendations of the Task Force).

## INTRODUCTION (3/3)

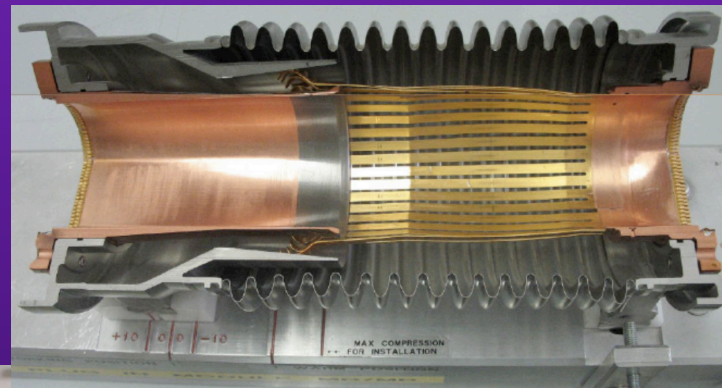
### ◆ **Mandate**

- Review the design of all components of the LHC equipped with RF fingers, evaluate the compatibility with ultimate (and HL-LHC) bunch populations (i.e. up to  $2.2E11$  p/b for the 25 ns beam and  $3.5E11$  p/b for the 50 ns beam) and (rms) bunch lengths (i.e. 7.5 cm but also  $\sim 4$  cm which could be an option) regarding impedance and HOM screening and provide a list of maximum bunch currents, acceptable bunch lengths etc.
- Evaluate all associated mitigation solutions like ferrite absorbers and their collateral effects, in particular the induced heating and resulting outgassing
- Make proposals of design changes and/or mitigation measures for each configuration depending on its criticality for beam operation
- Approve functional specifications for all equipments by the end of the year (2012)

# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (1/13)

- ◆ To avoid having too large impedances (longitudinal or transverse) due to (big) changes of geometry for moving equipments, which can lead to
  - Beam-induced RF heating (if real part of longitudinal impedance)
  - Longitudinal or transverse beam instabilities (if real and/or imaginary parts of longitudinal or transverse impedances)

- ◆ Example of RF fingers:  
PIMs = Plug-In Modules



- ◆ Example of ferrite tiles:  
Installed in the new VMTSA  
in 2012

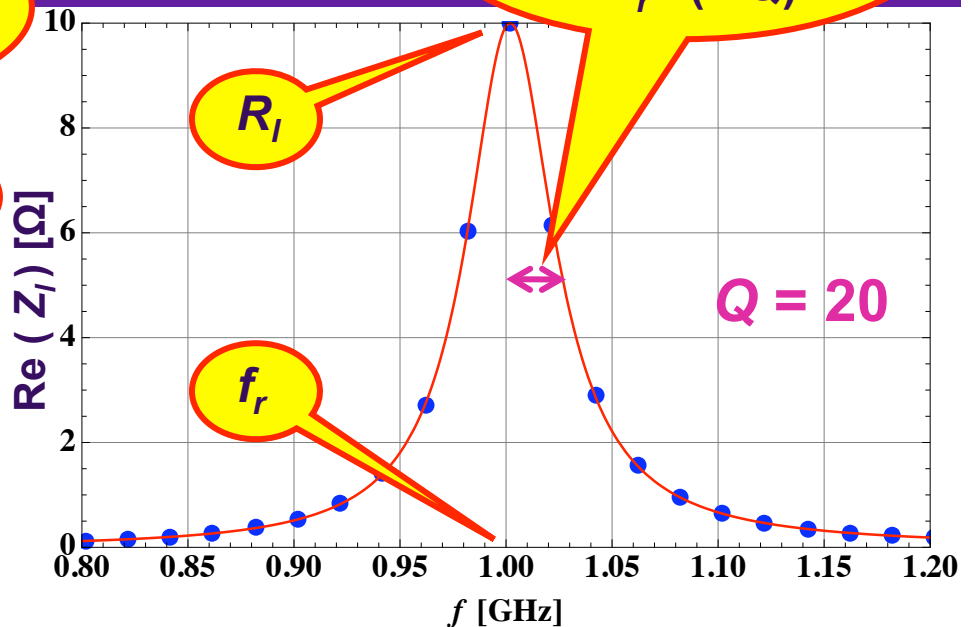
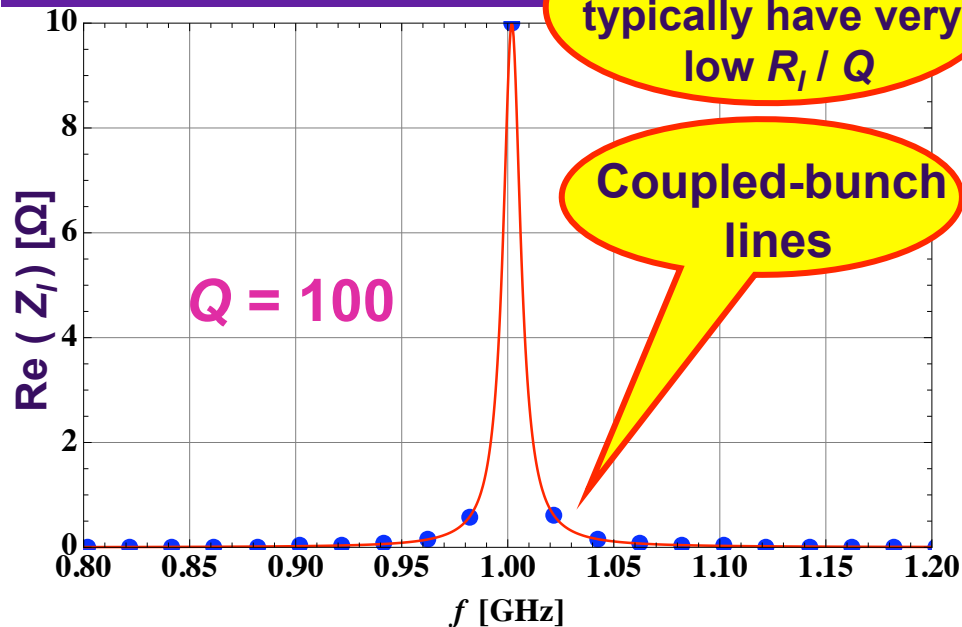


Initial dimensions  
(quickly available!):  
~ 12 cm × 3 cm × 1 cm

# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (2/13)

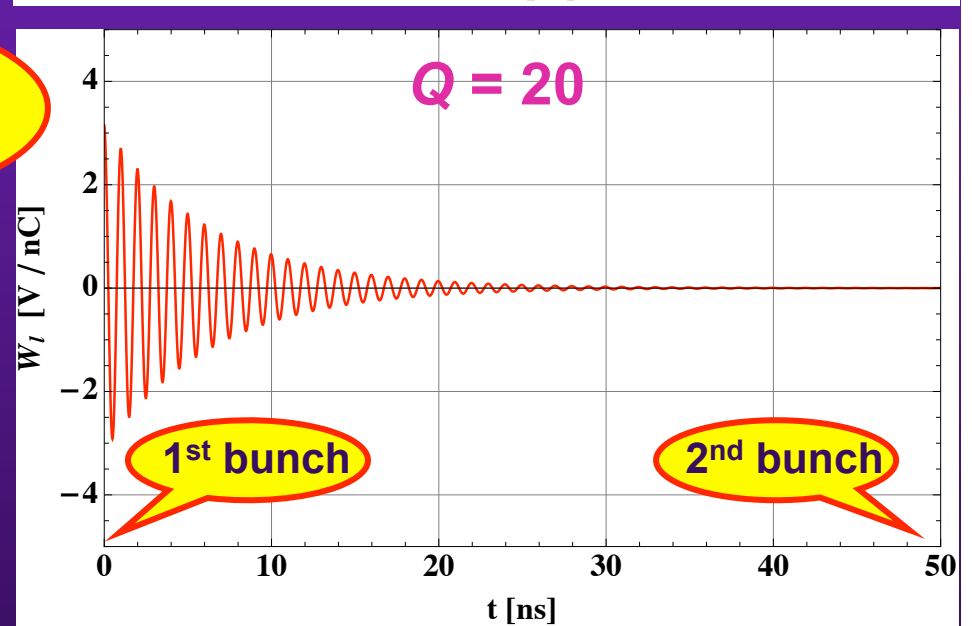
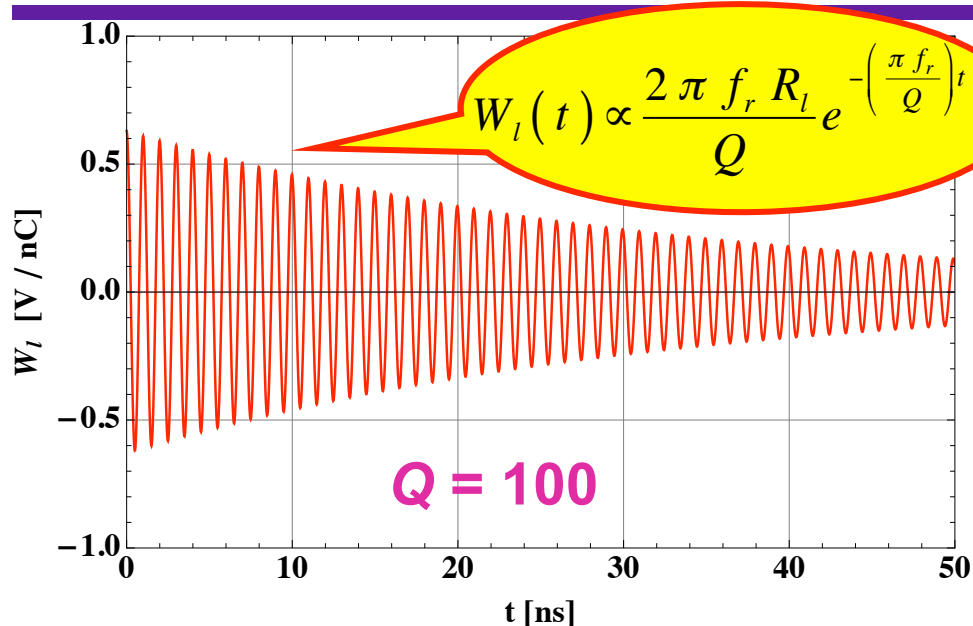
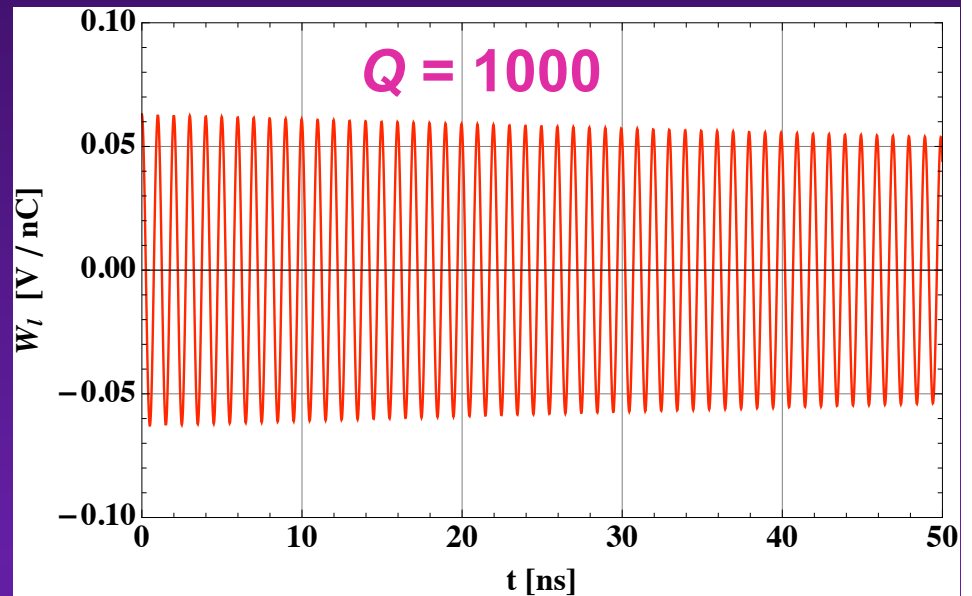
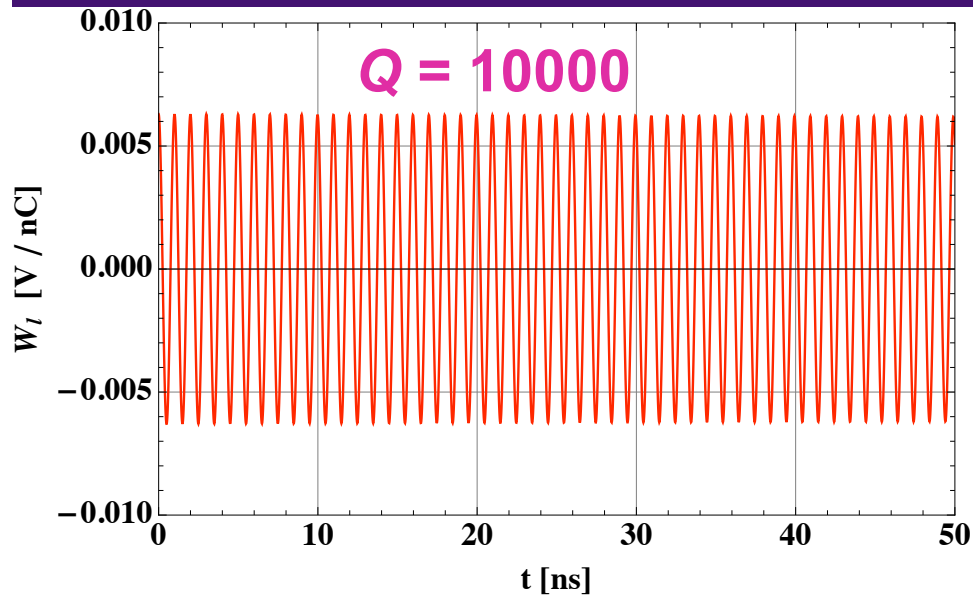
◆ Example for the RF heating => Consider the case of a narrow resonance (trapped mode due to the geometry) => 3 parameters (obtained from EM simulations):

- Resonance frequency => Assumed to be here  $f_r = 1$  GHz
- Shunt impedance => Assumed to be here  $R_l = 10 \Omega$
- Quality factor  $Q$  => Scanned below





# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (3/13)



# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (4/13)

- Power loss formula for the case of a (sharp) resonance (i.e. with only 1 line)

$$P_{loss} = (M I_b)^2 \times 2 R_l \times 10^{\frac{P_{dB}(f_r)}{10}}$$

Total beam current:

$M = \# \text{ bunches}$

$I_b = N_b e f_0$

$P_{dB}(f_r)$  is the power in dB read from a power spectrum (computed or measured) at the frequency  $f_r$

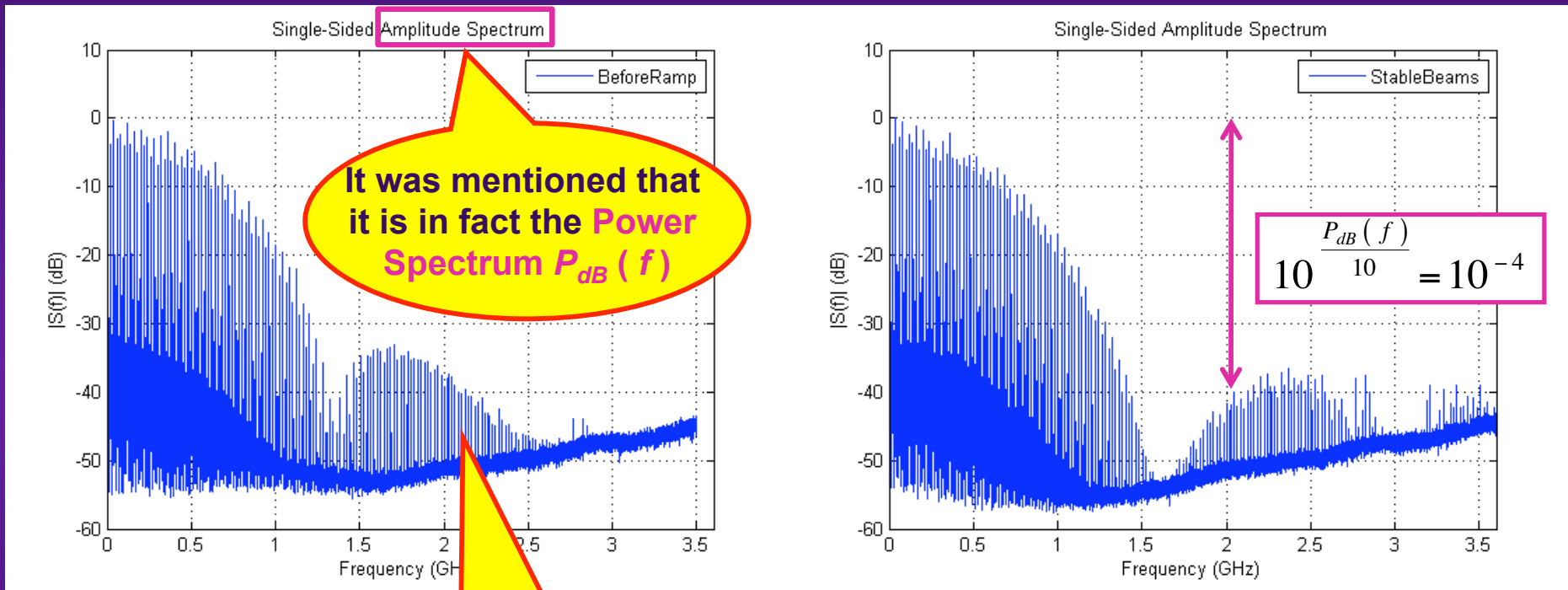
- ✧ A.N.:  $M = 1380$ ,  $N_b = 1.45E11 \text{ p/b} \Rightarrow M \times I_b = I_{total} \approx 0.36 \text{ A}$ ,  
 $R_l = 10 \text{ Ohm}$  and  $f_r = 1 \text{ GHz} \Rightarrow P_{dB}(1 \text{ GHz}) \approx -17 \text{ dB}$  (see next slide)  
 $\Rightarrow P_{loss} \approx 52 \text{ mW}$

- Note that in the case of a Gaussian bunch, the power loss is

$$P_{loss}^{Gaussian} = (M I_b)^2 \times 2 R_l \times e^{-(2\pi f_r \sigma_\tau)^2}$$

# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (5/13)

Measurements on B1 by ThemisM and PhilippeB on fill # 2261



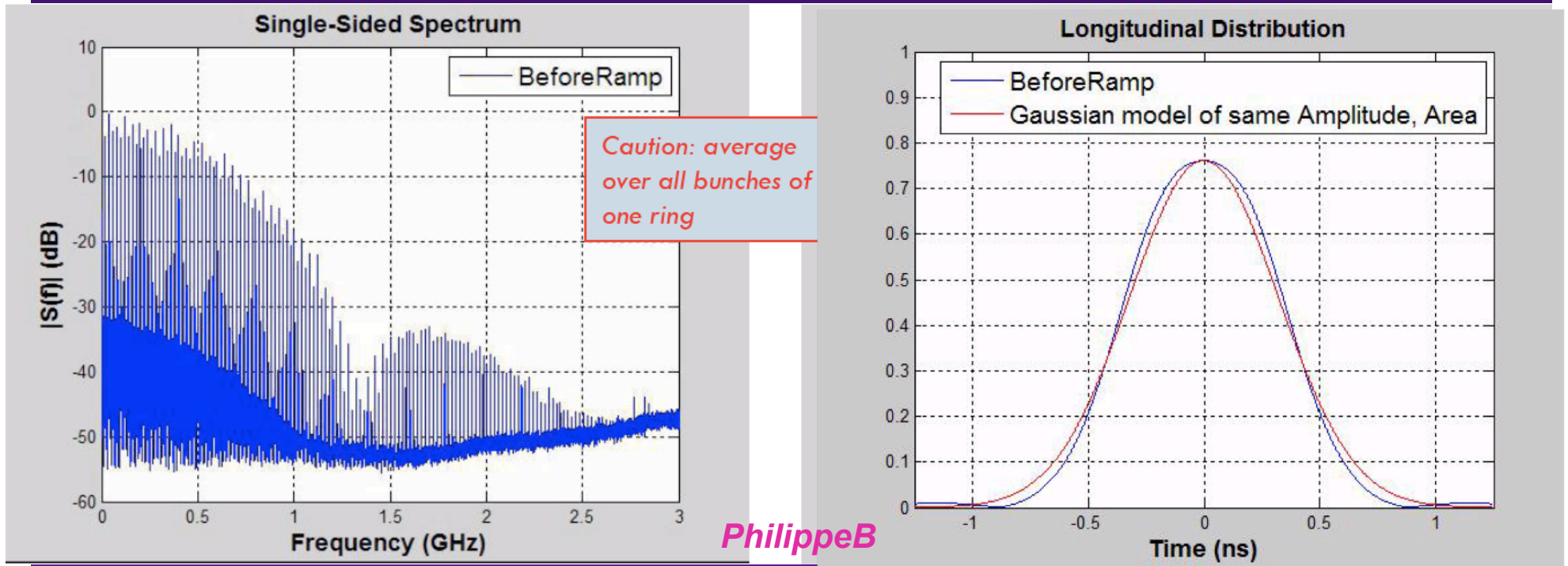
It was mentioned that it is in fact the Power Spectrum  $P_{dB}(f)$

Coupled-bunch lines spaced by  $M f_0 \sim 20$  MHz (for 50 ns bunch spacing) => It would be  $\sim 40$  MHz for 25 ns

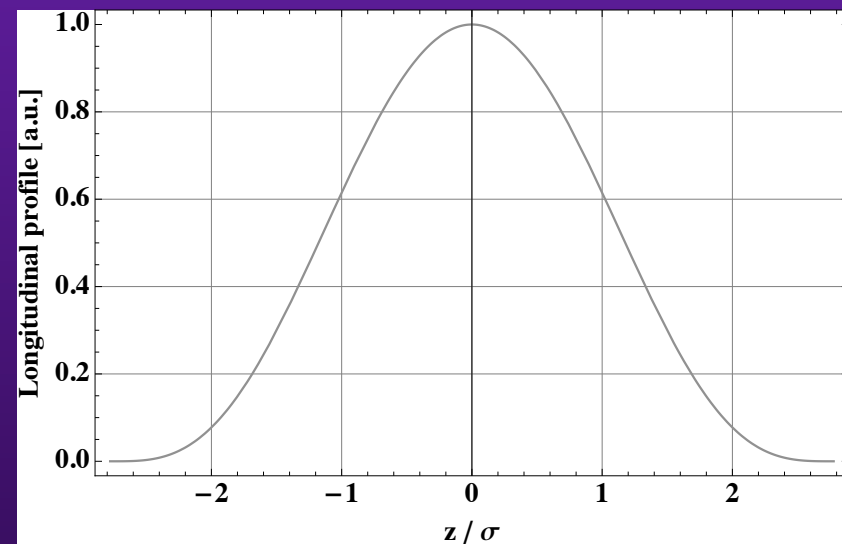
$$M_{50} = 1782$$

$$M_{25} = 3564$$

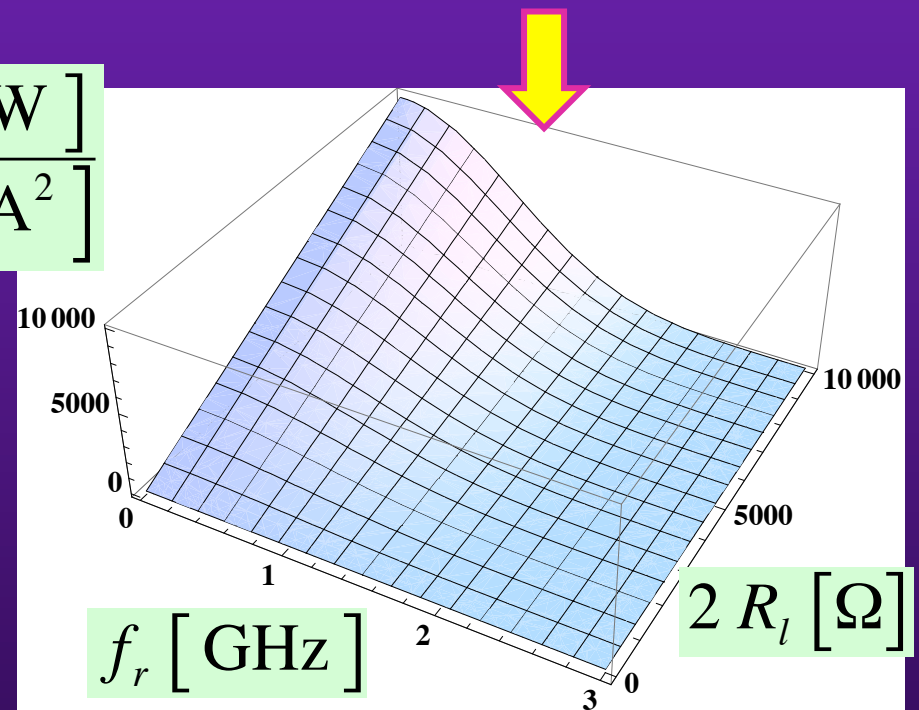
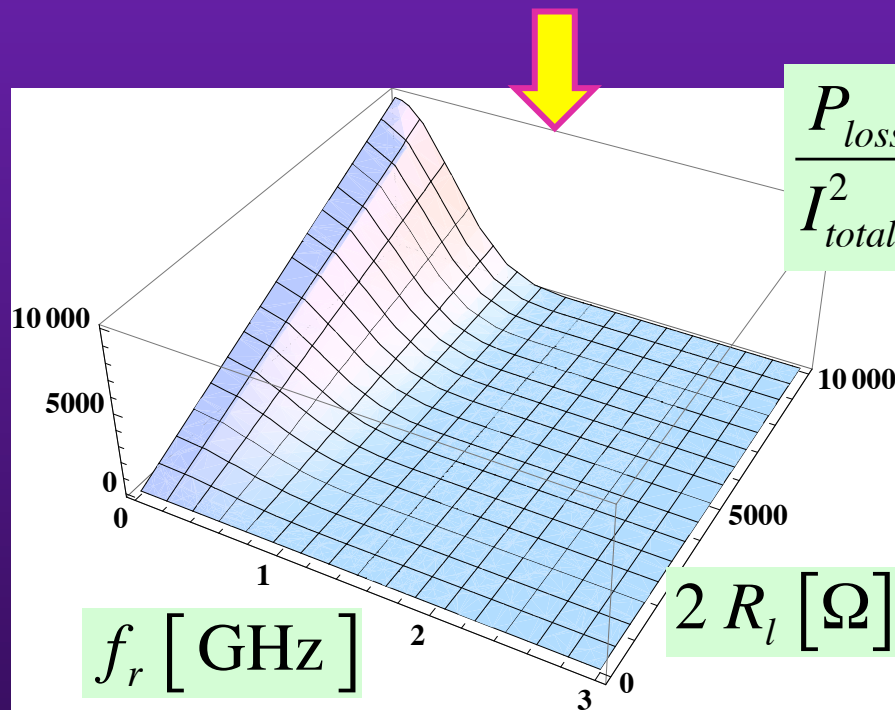
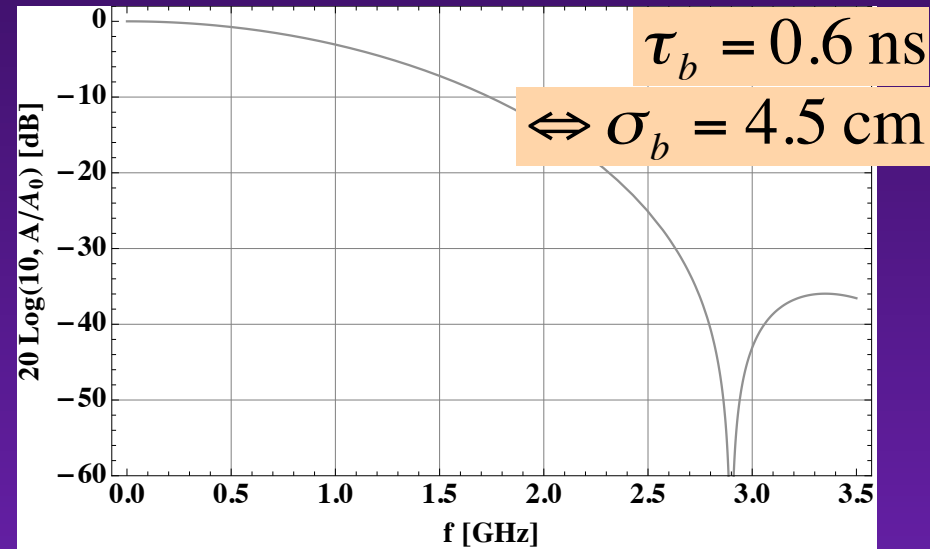
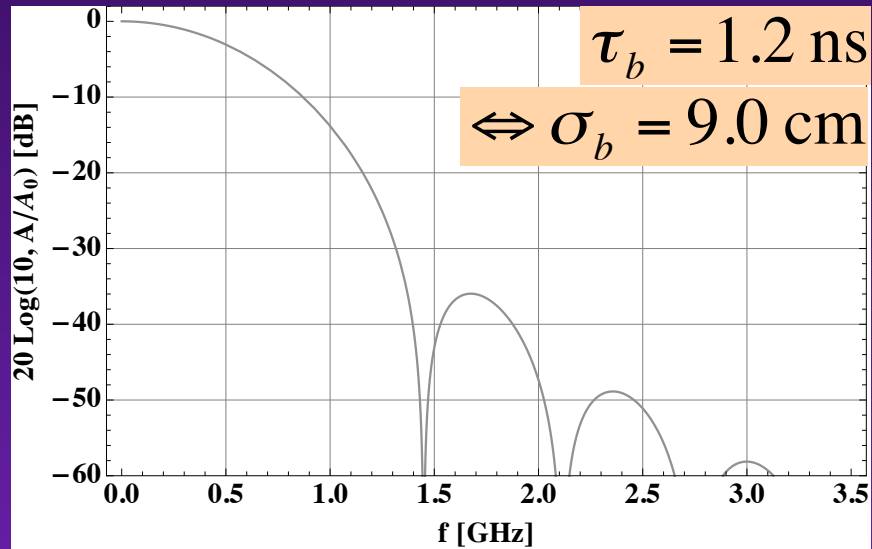
# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (6/13)



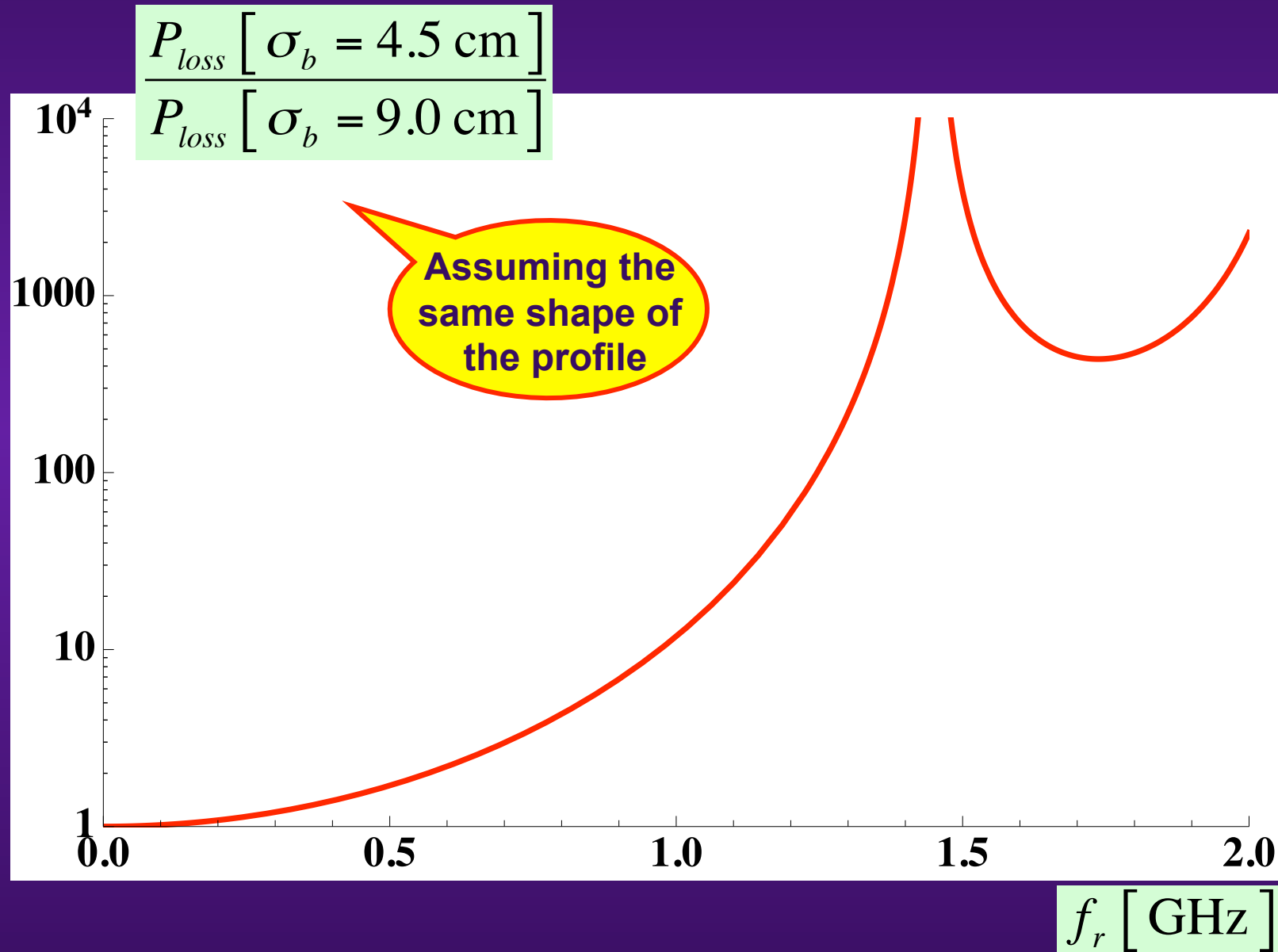
- Let's consider the following (analytical) distribution



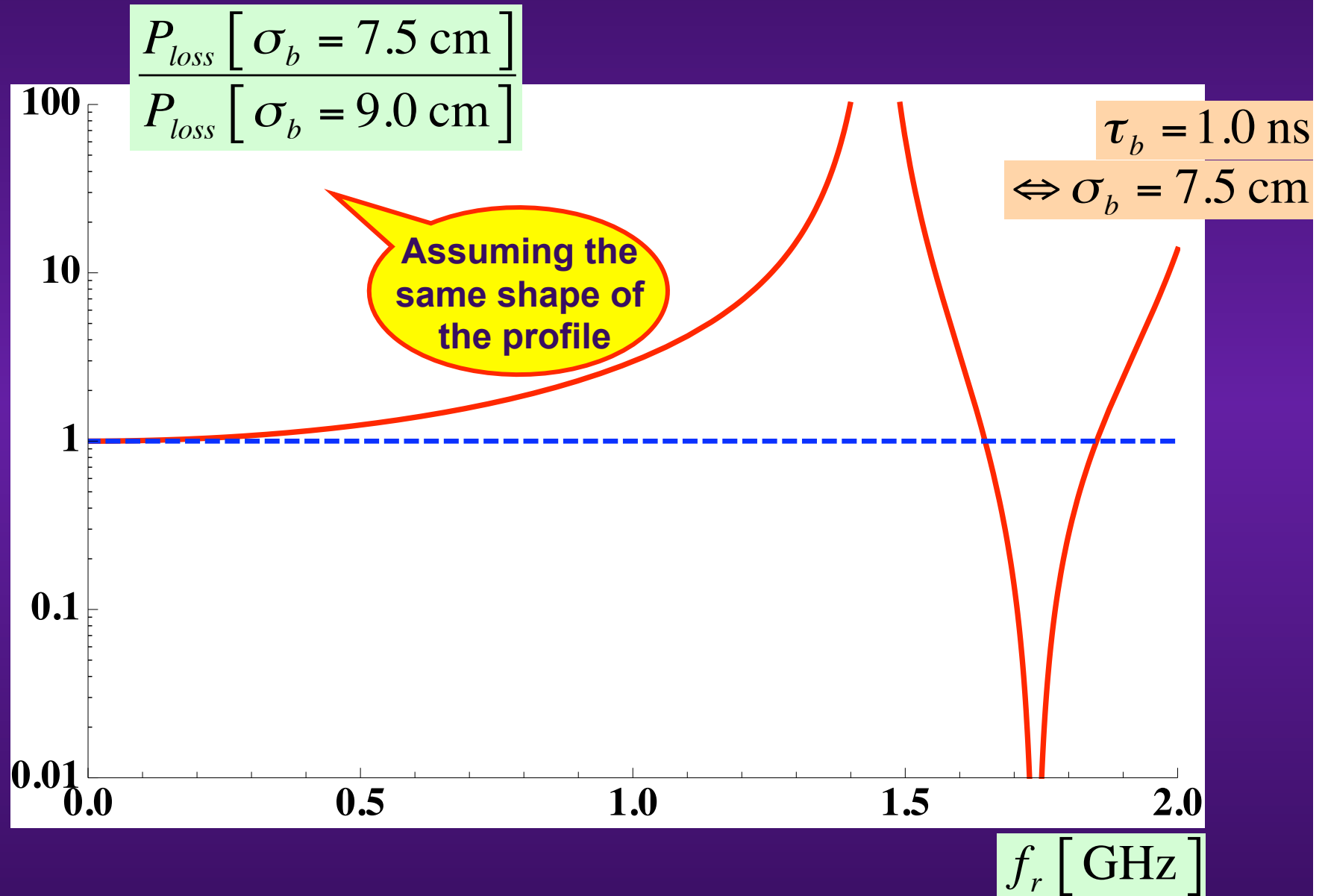
# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (7/13)



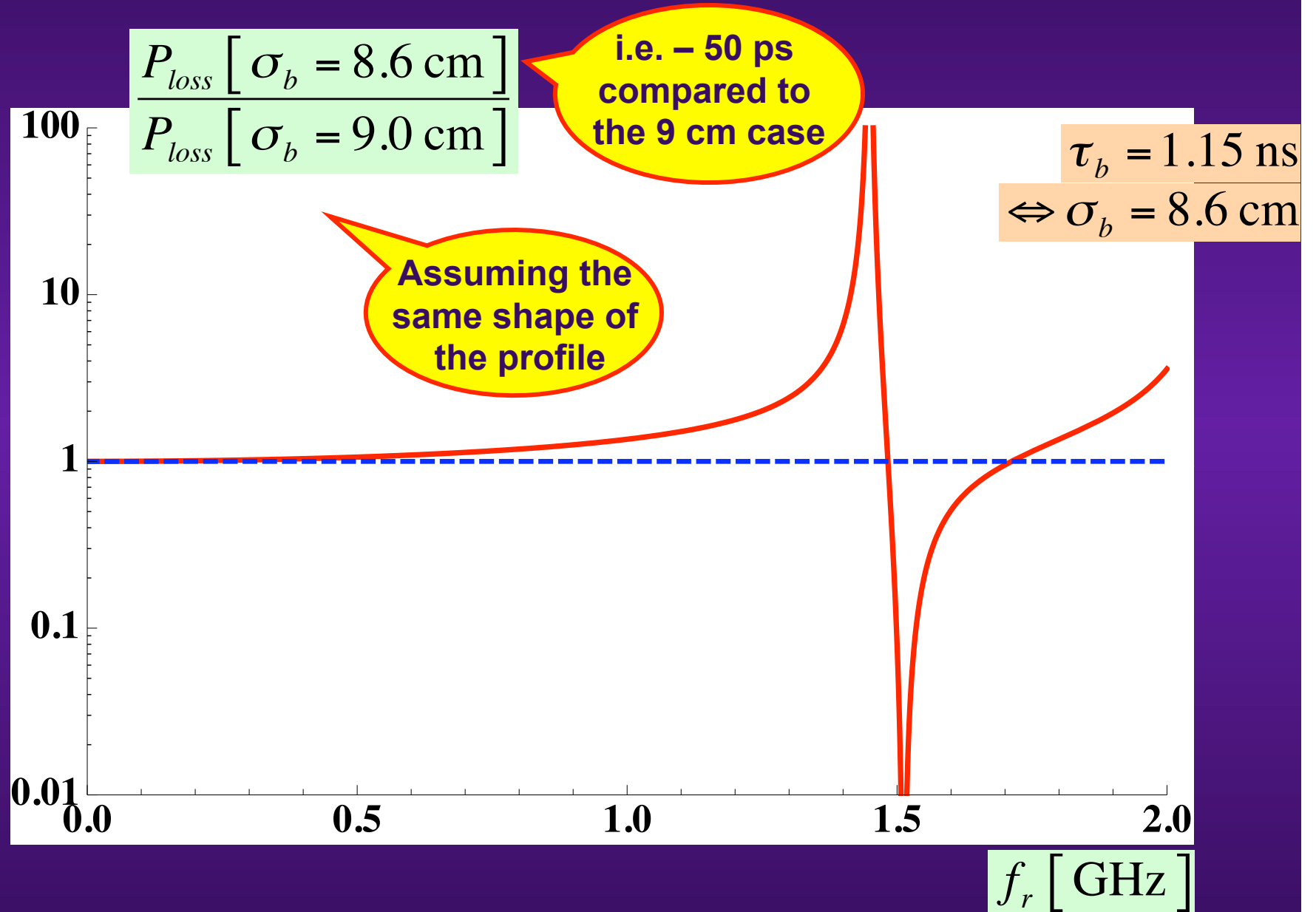
# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (8/13)



# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (9/13)

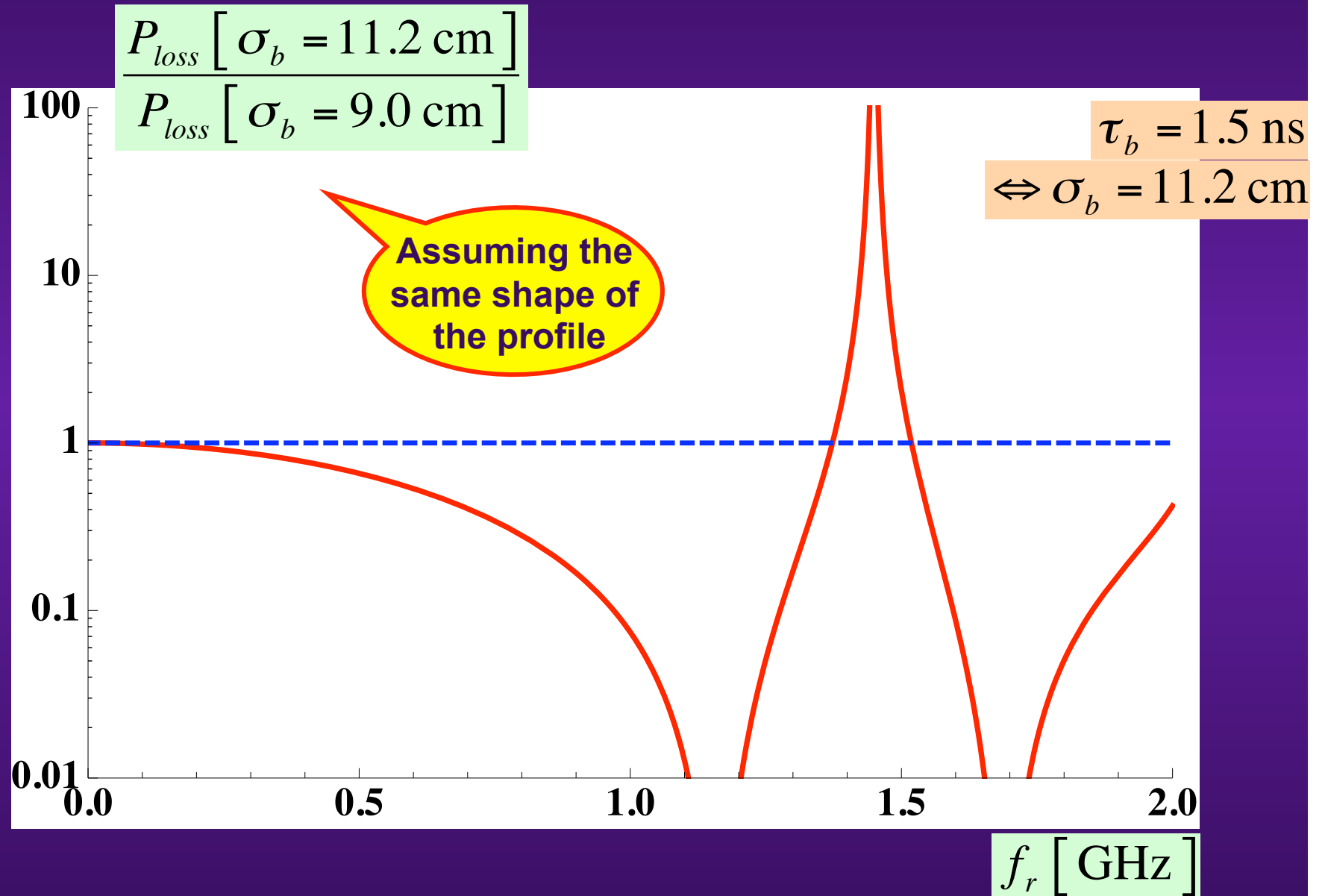


# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (10/13)

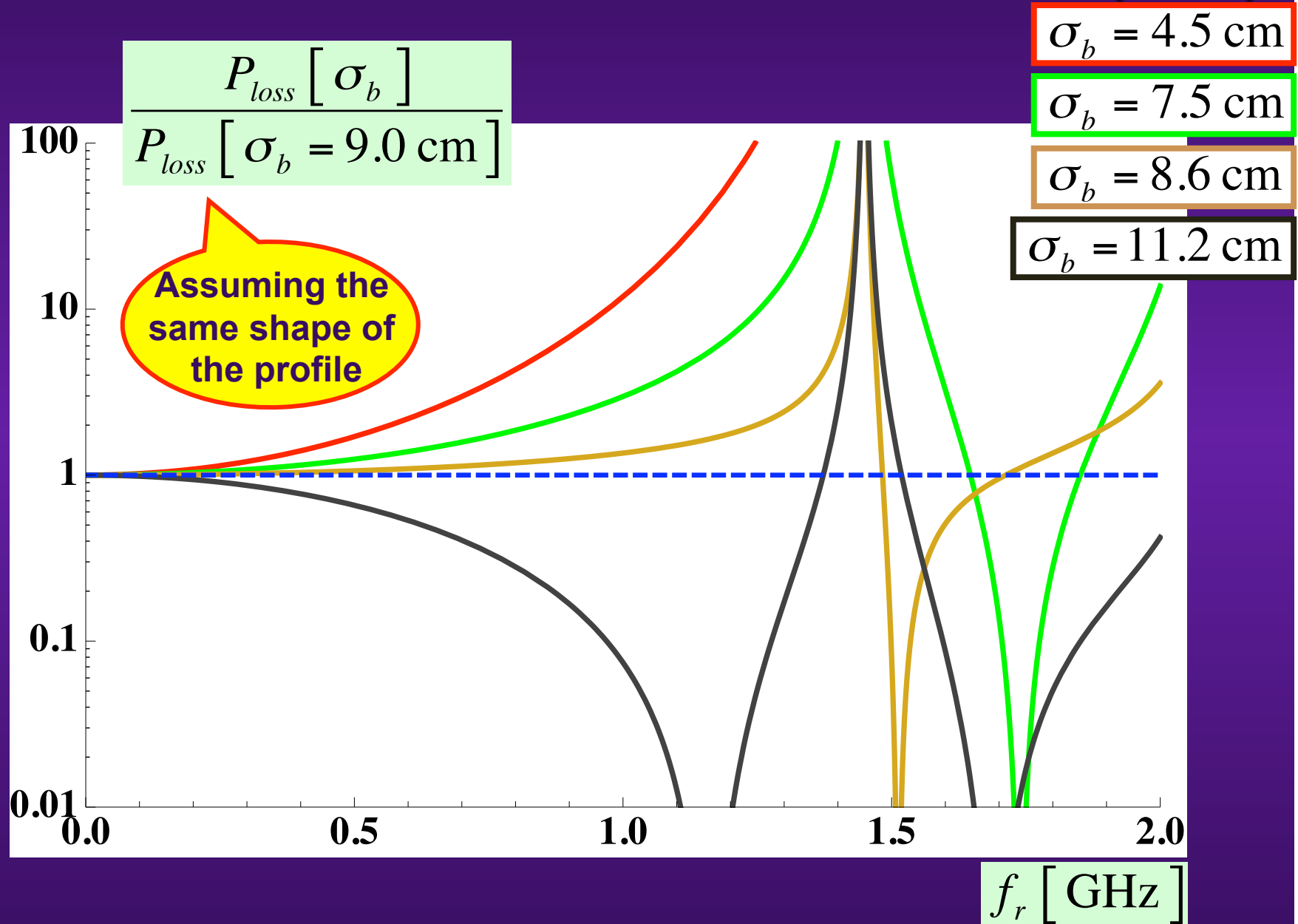




# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (11/13)



# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (12/13)



# WHY DO WE NEED RF FINGERS AND/OR FERRITE? (13/13)

## ◆ Example for the transverse instabilities => Case of the TCTVB (2-beam) collimator

- The simulated 2 most critical trapped modes

$$f_{r1} = 0.362 \text{ GHz}$$

$$Q_1 = 1700$$

$$R_{y1} = 152.8 \text{ M}\Omega/\text{m}$$

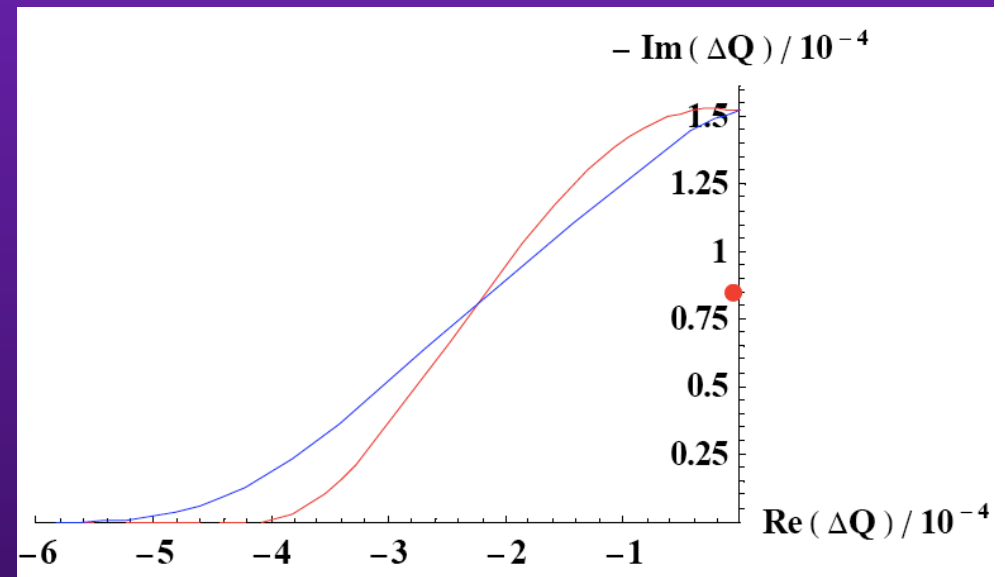
$$f_{r2} = 0.443 \text{ GHz}$$

$$Q_2 = 1080$$

$$R_{y2} = 173.8 \text{ M}\Omega/\text{m}$$

- Stability (octupoles only) at 7 TeV

- Close to the limit for nominal parameters and these impedances only!
- Ferrite (Ferroxcube 4S60) added to standard sliding contacts to damp HOMs



# WHAT WE PLANNED TO DO

- ◆ Exhaustive review of all the equipments with RF fingers
- ◆ Ranking by criticality and action plan
- ◆ First recommendations of the Task Force
- ◆ New design and/or mitigation measures
- ◆ List of endorsed actions presented by the Task Force => To be presented at the LMC

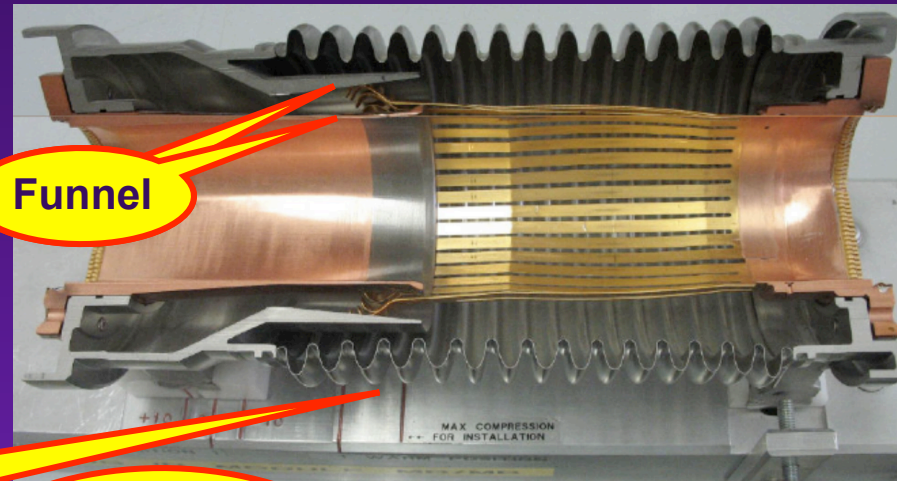
# WHAT WAS DONE

- ◆ 1) **Follow-up of the VMTSA: EM and heat transfer simulations**
- ◆ 2) **Review of past work and issue with the PIMs (what was wrong with the Plug-In Modules in the cold part of the LHC?)**
- ◆ 3) **Review of past development work on RF contacts**
- ◆ 4) **Review of equipments from TE/VSC, BE/BI, TE/ABT, collimators from EN/STI-MME (and past impedance studies with RF fingers), wake field suppressor in the LHCb VELO**
- ◆ 5) **New design for RF fingers proposed by TE/VSC and impedance studies**
- ◆ 6) **Review of nonconformities in warm modules following the X-ray campaign => Typical defects and complete list of all of them**
- ◆ 7) **Review of recent contacts' issues in the SPS (after 35 years without any problem) => In power transmission lines (not machine)**
- ◆ 8) **Guidelines for the use of ferrite: EM and heat transfer simulations**

# SEVERAL DESIGNS FOR RF FINGERS (1/5)

## ◆ 1) Funnel for the PIMs

- For case of longitudinal movement (only)
- Good for contact / gap
- Possible issue with buckling and aperture restriction



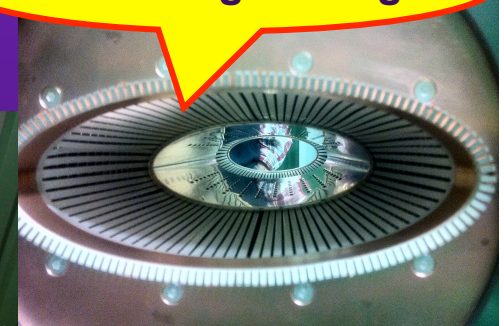
RF contact fingers to shield the distorted geometry of the bellows from the beam

Spring (to be put at the extremity of the RF fingers where there is a groove)

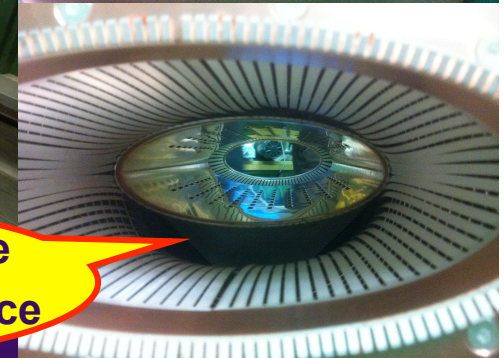
Conforming RF fingers

## ◆ 2) Spring for the VMTSA

- For case of transversal movement
- Possible issue with contact / gap (due to elliptical shape) => RF heating
- Possible issue with aperture restriction



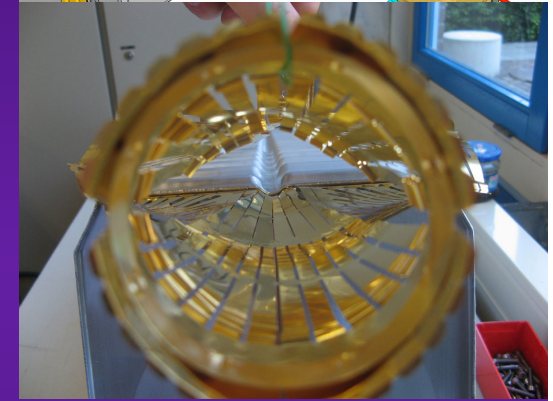
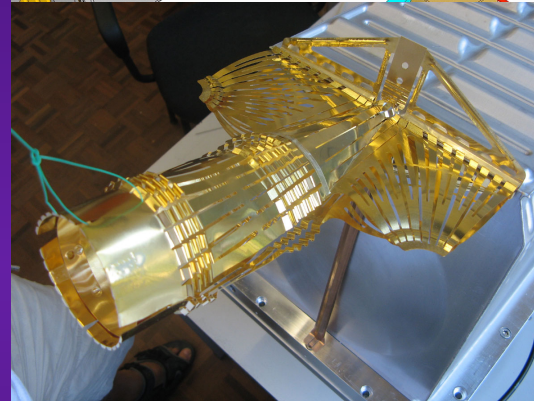
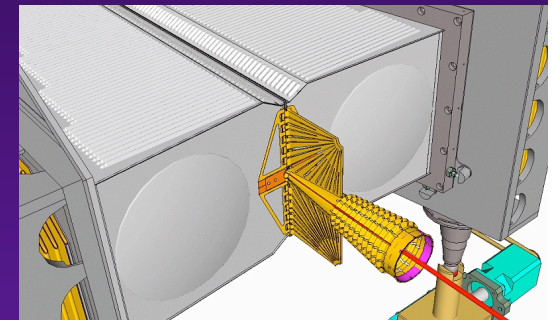
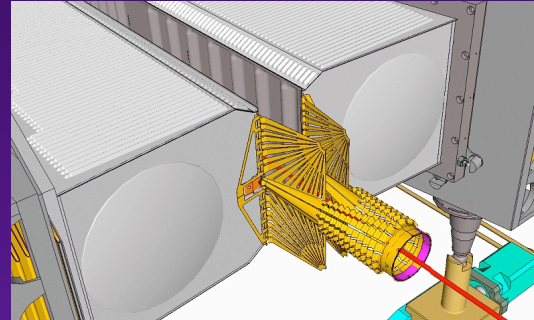
Big gap created in case the spring is NOT in place



## SEVERAL DESIGNS FOR RF FINGERS (2/5)

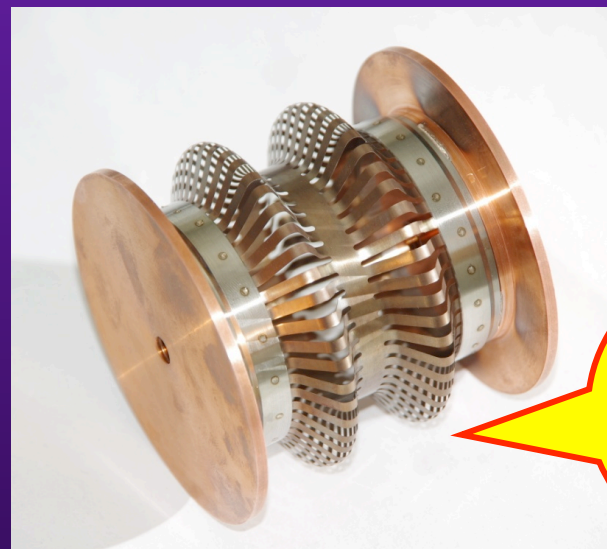
### ◆ 3) Fixed extremities for the LHCb VELO (VERtex LOcator)

- Seems to work very well!
- Well-studied VELO design in terms of impedance effects paid off => No issue observed
- Future upgrade: Reduction of the inner radius of the foil (from 5.5 to 3 – 4 mm)



### ◆ 4) New RF design from TE/VSC

- 1<sup>st</sup> prototype based on 2 convolutions manufactured this year. Tests ongoing
- Issue: Imaginary part of the longitudinal impedance (if many)



Device EM longer than mechanically due to induced current having to follow the convolutions

## SEVERAL DESIGNS FOR RF FINGERS (3/5)

- The longitudinal impedance depends on how much the RF fingers are stretched
- The impedance is close to zero in either completely compressed state or completely stretched state
- The maximum normalized longitudinal impedance is

$$\text{Im} [Z_l / n] \approx 1.5 \cdot 10^{-4} \Omega$$

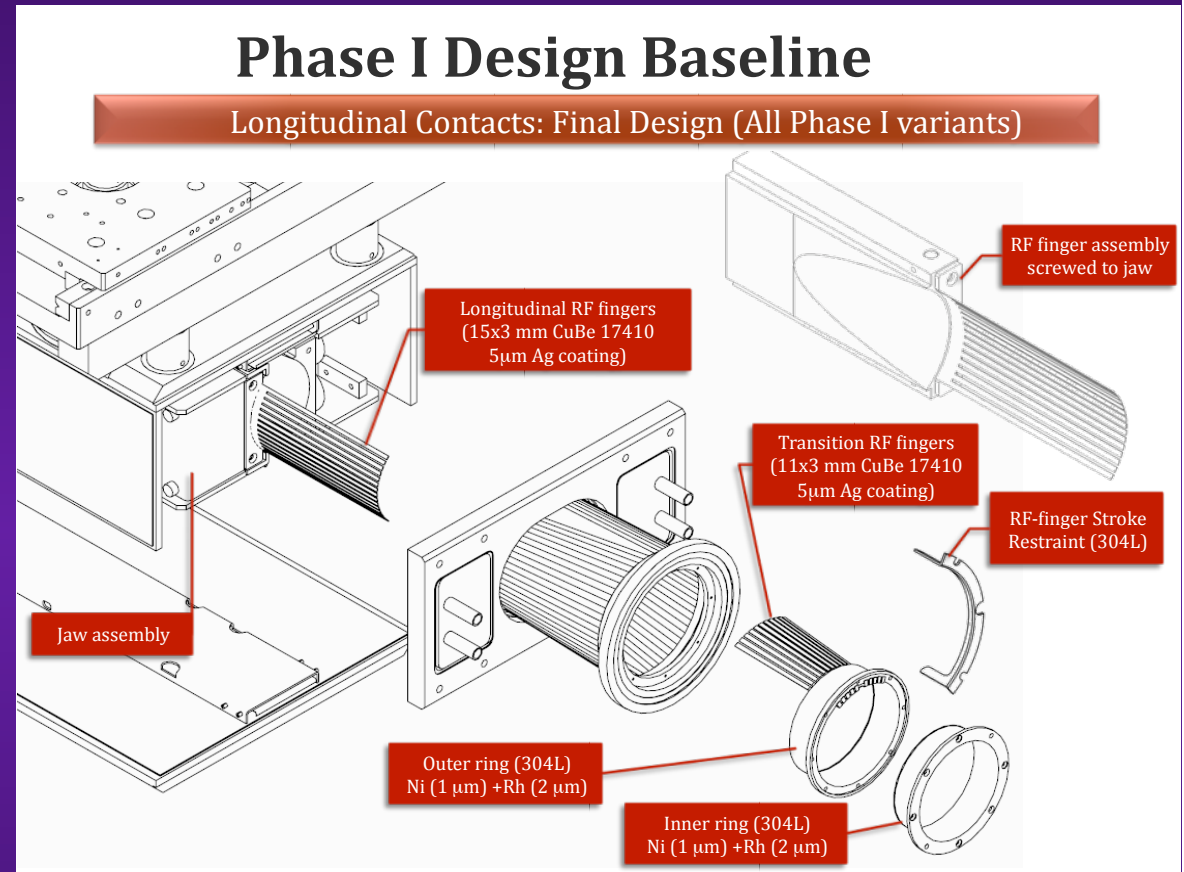
- Should not be used for all the PIMS for instance as the total LHC budget is  $\sim 0.1 \Omega$  (i.e. only 667 times more) and there are  $\sim 1700$  PIMs / ring



# SEVERAL DESIGNS FOR RF FINGERS (4/5)

## ◆ 5) Longitudinal sliding contacts for collimators

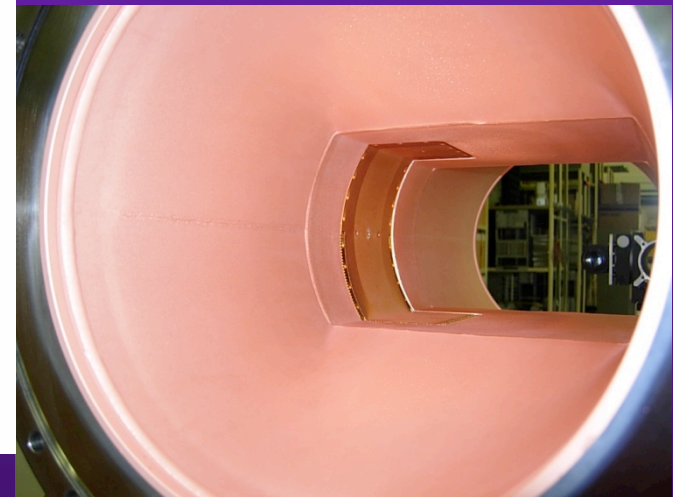
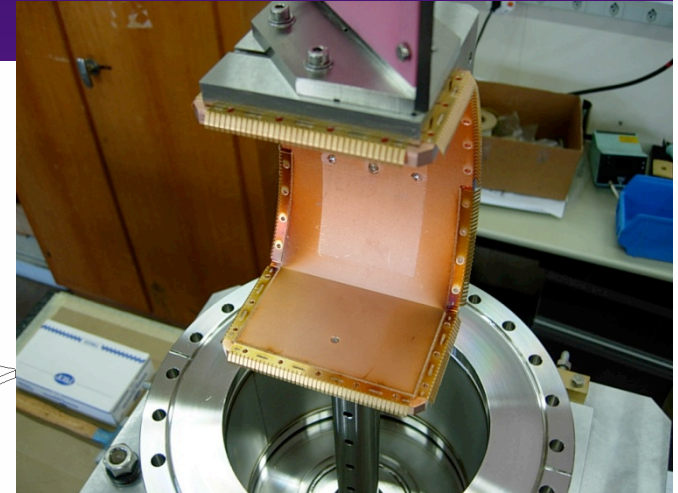
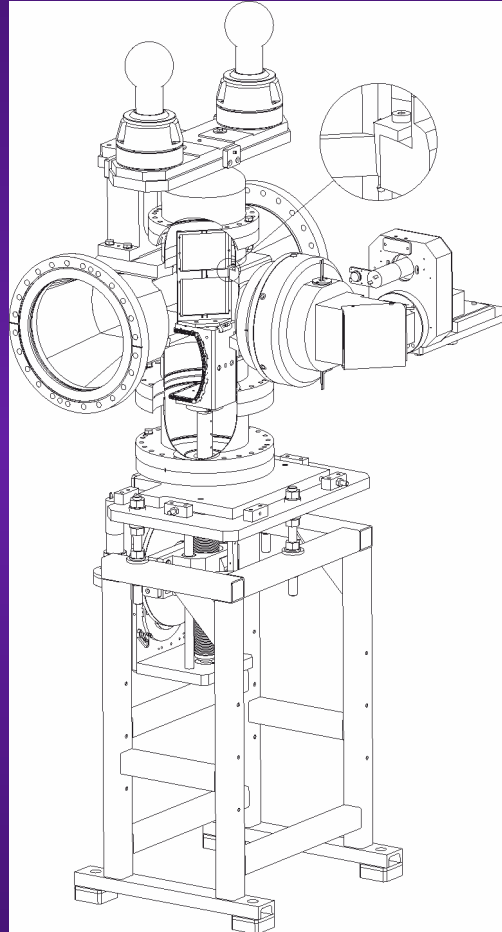
- Initial proposal for 1<sup>st</sup> (SPS) prototype (2003)
- Uncoated CuBe fingers sliding on C/C
- Electrical contact resistance  $\sim 30 \text{ m}\Omega$  (specification:  $1 \text{ m}\Omega$ )  
=> Redesign necessary



# SEVERAL DESIGNS FOR RF FINGERS (5/5)

## ◆ 6) Sliding contacts for BTVs

- Both beams inside the vacuum chamber
- RF contacts all along the moving parts
- Specifications: movement up and down. Very rare (1 or 2 last year). In front of MKI and next to TDI
- They cannot be completely bake out (due to screen etc.) and they are close to equipments very demanding for outgassing => Possibility to remove them?



# POSSIBLE ISSUES TO CONSIDER WITH RF FINGERS (1/2)

## ◆ RF fingers for PIMs

- Low contact resistance  $< 0.1 \text{ m}\Omega$  (i.e.  $3 \text{ m}\Omega$  / RF finger as there are 30 RF fingers in //)
- No cold welding
- Low friction
- Good formability properties

## ◆ RF fingers for collimators

- Same as above with contact resistance  $< 1 \text{ m}\Omega$
- Resistance to bake out:  $250^\circ\text{C}$  / 1000 h
- Resistance to heating  $\Rightarrow$  Good thermal conductivity
- Wear after many cycles “open-close of the jaws” (1500 cycles  $\sim$  4 years)

## ◆ Good electric contacts requires

- Low surface roughness
- Soft metals (at least one)
- No oxide layer at the surface

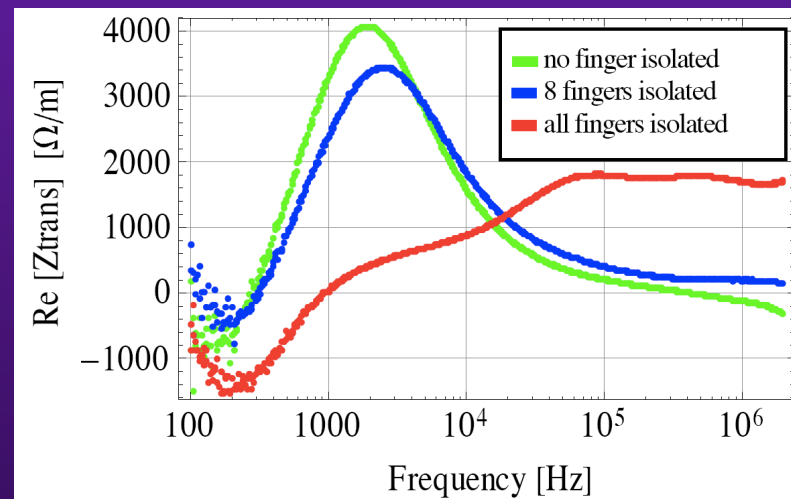
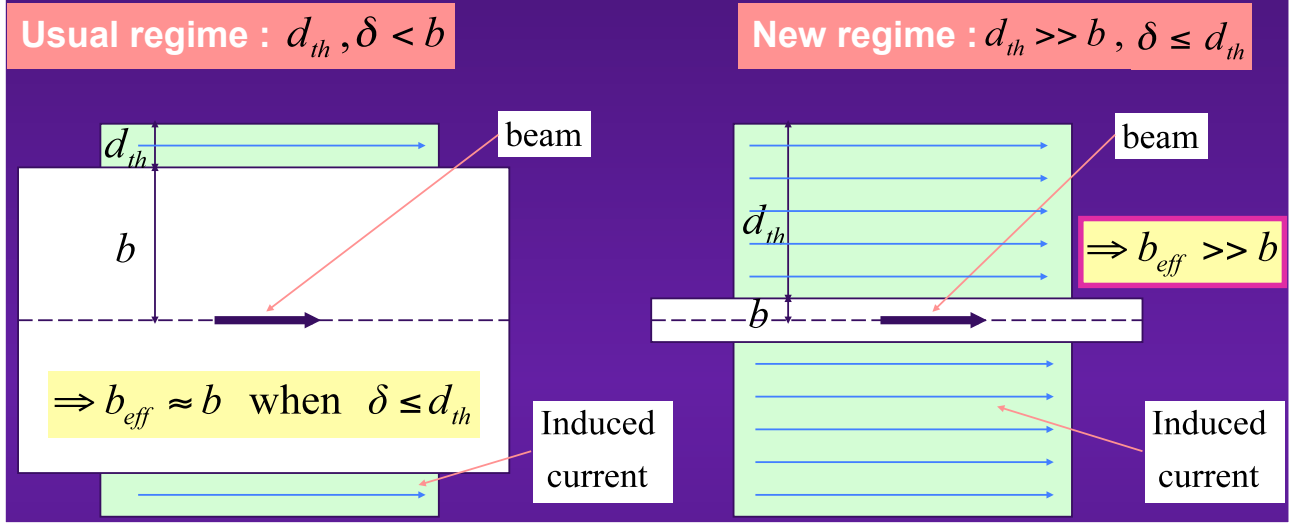
# POSSIBLE ISSUES TO CONSIDER WITH RF FINGERS (2/2)

- Resistive - Wall impedance for LHC collimators

New findings have been made over the last few years for the impedance at low frequency => Bad conductor is better! But high frequency also important...

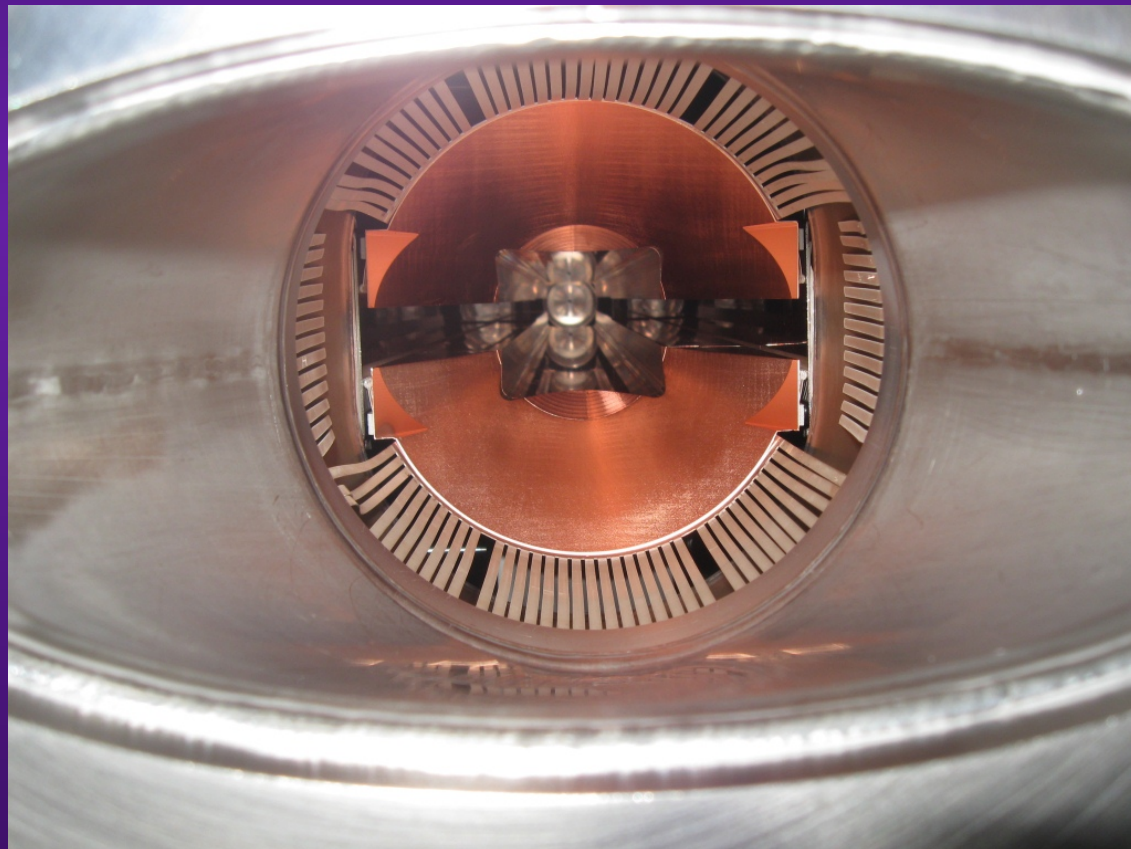
- Contact resistance for the PIMs

=> A new physical regime was revealed by the LHC collimators: the resistive impedance is ~ 2 orders of magnitude lower at ~ 8 kHz!



# EXAMPLE OF A KNOWN RF FINGER ISSUE WITH A TCDD

- ◆ **Example of the TCDD of sector A4L2 with some RF fingers badly bent**
  - Known pb which has been solved for the Phase I collimators: the RF-finger stroke restraint piece (304L) was added for that



# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (1/8)

- ◆ 1800 X-rays taken
- ◆ 92 NC (~ 5 %)
- ◆ 58 vacuum sector concerned out of 190 at room temperature (88 sectors at cryogenic temperature)

## 3.1 CRITÈRES D'ACCEPTATION

- Ressort de traction:

Tout ressort de traction hors de son logement ou manquant sur les radiographies sera considéré comme **non conforme**.

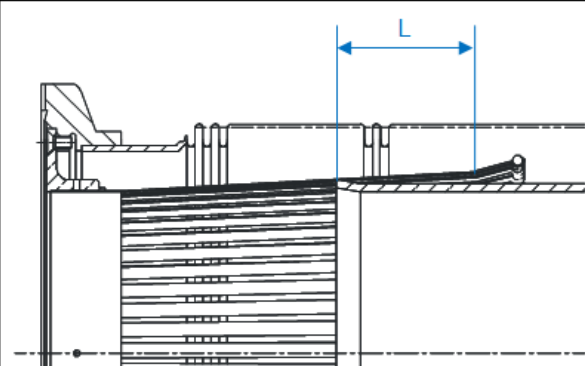
- Doigt RF:

Tout doigt RF déformé ou non maintenu par le ressort de traction sera considéré comme **non conforme**.

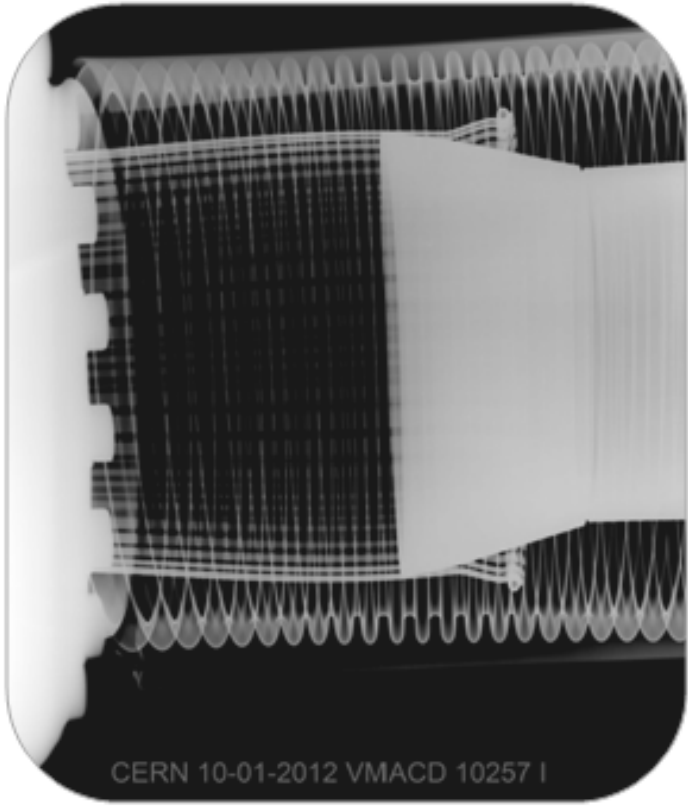
- Distance de recouvrement:

Les tolérances de fonctionnement d'un « Warm Module » sont de 0/+10mm par rapport à la longueur d'installation indiquée dans la BD (par exemple, la longueur maximale d'installation d'un module de 200mm est de 210mm).

Les limites d'acceptation de la distance de recouvrement dans un « Warm module » sont indiquées dans le tableau ci-dessous.

	<p>Si la longueur L est égale à 15mm, la distance de recouvrement est conforme.</p> <p><math>0 &lt; L \leq 15\text{mm}</math> CONFORME</p>
	<p>Si la longueur L est nulle, la distance de recouvrement est <b>non conforme</b>.</p> <p><math>L \leq 0</math> NON CONFORME</p>

# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (2/8)

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMACD	300	Secteur : A7R4.B  10256.6962	I	10-01-2012  (A.Piguet)	 <p>CERN 10-01-2012 VMACD 10257 I</p>
<b>Ressort de traction</b>			Conforme		
<b>Doigt RF</b>			Conforme		
<b>Distance de recouvrement</b>			Conforme		
<b>Action</b>			Aucune		

# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (3/8)

- Spring out
- Deformation
- Zero length overlap

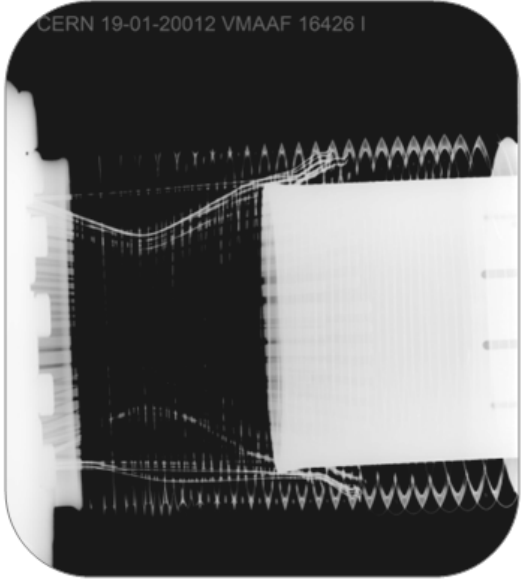
Possible buckling and/or arcing => Very unhealthy

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMAAB	300	Secteur : A7R4.B 10176.6962	I	30-03-2011 (A.Piquiet)	
<b>Ressort de traction</b>			Ressort de traction hors de son logement		
<b>Doigt RF</b>			Légère déformation de l'extrémité supérieure		
<b>Distance de recouvrement</b>			Distance nulle		
<b>Action</b>			Module à démonter pour réparation et correction d'alignement longitudinale nécessaire		



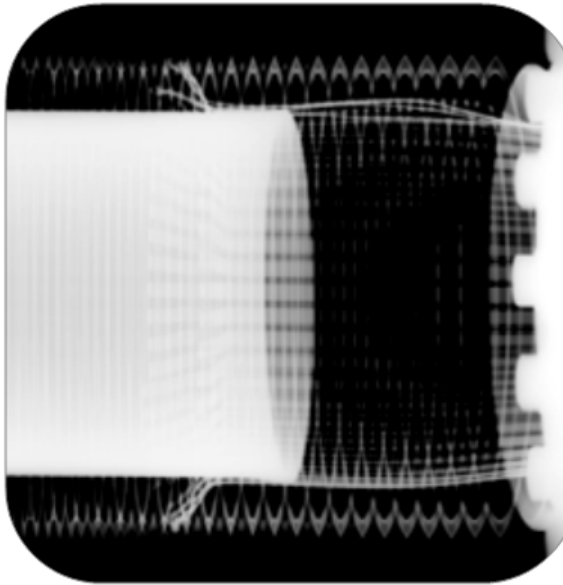
# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (4/8)

- Spring out
- Deformation
- Aperture restriction
  - beam is passing trough since years

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMAAF	300	Secteur: C5L6.R 16426.357	I	19.01.2012 (A.Piguet)	
<b>Ressort de traction</b>			Ressort de traction hors de son logement !		
<b>Doigt RF</b>			Doigts RF bloqués et déformés dans les ondes du soufflet et réduction d'ouverture très importante !		
<b>Distance de recouvrement</b>			Conforme		
<b>Action</b>			Module à démonter pour réparation		

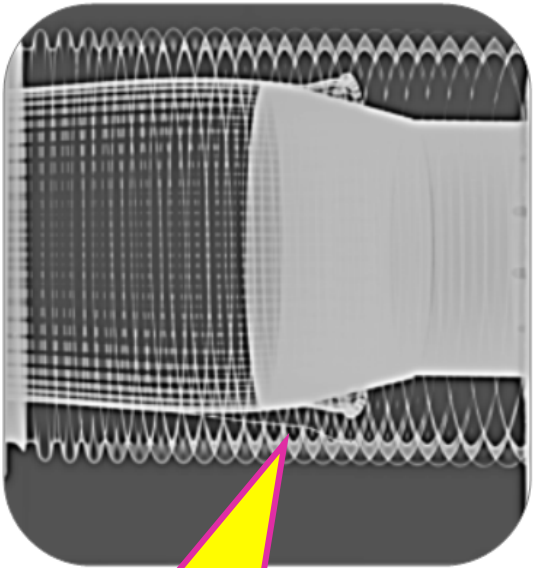
# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (5/8)

- Spring out
- RF fingers blocked
- Overlap acceptable

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMAAB	300	Secteur: C5L6.R 16442.470	I	19.01.2012 (A.Piguiet)	
<b>Ressort de traction</b>			Ressort de traction hors de son logement !		
<b>Doigt RF</b>			Doigts RF bloqués et déformés dans les ondes du soufflet !		
<b>Distance de recouvrement</b>			Conforme		
<b>Action</b>			Module à démonter pour réparation		

# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (6/8)

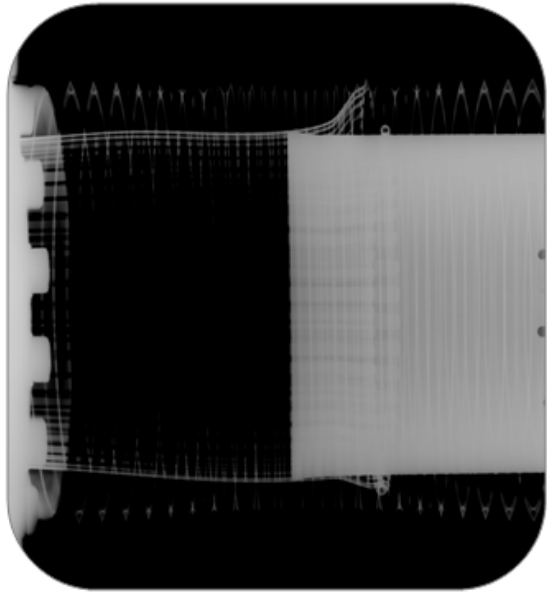
- Spring in place
- 1 RF finger out
- Overlap acceptable

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMAND	290	Secteur: C5L6.R 16449.770	I	19.01.2012 (A.Piguet)	
<b>Ressort de traction</b>			Conforme		
<b>Doigt RF</b>			Montage d'un doigt RF défectueux !		
<b>Distance de recouvrement</b>			Conforme		
<b>Action</b>			Module à démonter pour réparation		

1 RF finger out but not with the spring attached to it is a better situation than with the spring attached to it (see VMTSA study later)

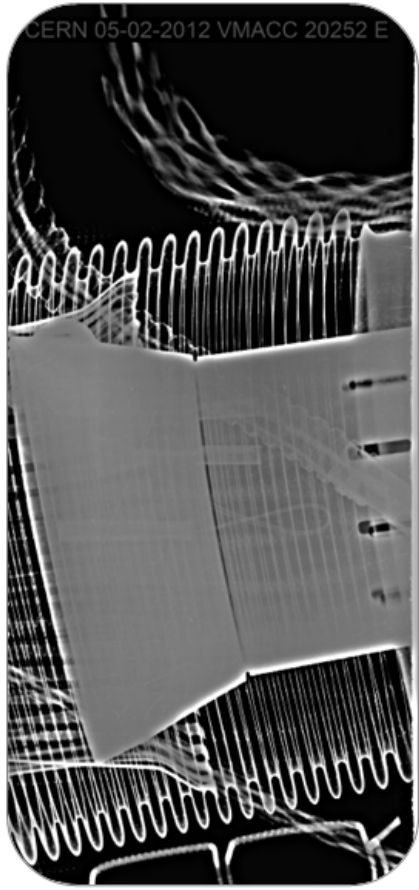
# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (7/8)

- Spring in place
- some RF fingers out
- Overlap acceptable

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMAAE	300	Secteur : A7R1.R  245.866	<b>I</b>	09-12-2011  (A.Piguiet)	
<b>Ressort de traction</b>			Conforme		
<b>Doigt RF</b>			Doigts RF défectueux !		
<b>Distance de recouvrement</b>			Conforme		
<b>Action</b>			Module à démonter pour réparation		

# TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (8/8)

- Spring out
- RF fingers blocked
- Overlap acceptable
- Triggered a BD of fill 2978
- Increase vacuum interlock => use as is for beam vacuum performances

Module	Longueur (mm)	Position (DCUM)	Ligne	Date	Radiographie
VMACC	300	Secteur : A7R7.B 20251.9914	E	05.02.2012 (A. Piguier)	
<b>Ressort de traction</b>			<b>Ressort de traction hors de son logement !</b>		
<b>Doigt RF</b>			<b>Doigts RF bloqués dans les ondes du soufflet !</b>		
<b>Distance de recouvrement</b>			Conforme		
<b>Action</b>			<b>Module à démonter pour réparation</b>		

# LIST OF ALL NONCONFORMITIES (1/3)

Satus 3-9-2012							
#	LSS	VACSEC	Name	DCUM	nature	niveau de non conformite	
1	LSS1	A4L1.C	VMBGG	26525.3832	Ressort hors logement	2	
2	LSS1	A4L1.C	VMBGA	26544.2832	Ressort hors logement	2	
3	LSS1	A4L1.C	VMBGG	26563.1832	distance recouvrement nulle	2	
4	LSS1	A4L1.C	VMCKB	26573.8872	absence de contact, demontage pour echange ressort	2	
5	LSS1	A4L1.C	VMCKB	26578.1272	absence de contact, demontage pour echange ressort	2	
6	LSS1	A4L1.C	VMCKG	26582.3932	absence de contact, demontage pour echange ressort	2	
7	LSS1	A4L1.C	VMCKB	26586.6592	absence de contact, demontage pour echange ressort	2	
8	LSS1	A4L1.C	VMCKG	26590.9252	absence de contact, demontage pour echange ressort	2	
9	LSS1	B1L1.X	VMAAA	26600.7112	distance recouvrement nulle	2	
10	LSS1	A4R1.C	VMCKG	76.016	distance recouvrement nulle	2	
11	LSS1	A4R1.C	VMBGA	101.6	Ressort hors logement, doigts deforms et bloques	2	
12	LSS1	A4R1.C	VMBGG	133.1	Doigts Rf a l'interieur insert, ressort autour doigts mais hors logement	2	
13	LSS1	A4R1.C	VMEGB	139.4	absence d'insert RF	1	
14	LSS1	A4R1.C	VMZAW	144.72	absence totale de contact, demontage pour echange ressort	1	
15	LSS1	A7R1.R	VMAAE	245.866	Quelques doigts hors ressort	2	
16	LSS2	A6L2.B	VAMSF	3139.5124	ressort hors logement	2	
17	LSS2	C1L2.X	VMAAA	3263.0624	distance recouvrement nulle	2	
18	LSS2	B1R2.X	VMAAA	3401.4584	distance recouvrement nulle	2	
19	LSS3	A7L3.R	VMAAE	6425.1158	Ressort hors logement	2	
20	LSS3	A4L3.R	VMGLA	6642.3808	distance recouvrement nulle	2	
21	LSS3	IP3.R	VMGLA	6686.8608	Ressort hors logement, doigt au milieu (!?)	1	
22	LSS4	A7L4.R	VMAAB	9743.6662	Ressort hors logement	2	
23	LSS4	A7L4.R	VMAAE	9780.1662	Ressort hors logement	2	
24	LSS4	E5L4.R	VMAAA	9881.6222	distance recouvrement nulle	2	
25	LSS4	B5L4.B	VMADE	9963.7292	insert Rf inverses	3	
26	LSS4	B5L4.B	VMADF	9973.1992	insert Rf inverses	3	
27	LSS4	B5L4.R	VMADE	9973.1992	insert Rf inverses	3	
28	LSS4	B5R4.R	VMADF	10020.6632	insert Rf inverses	3	
29	LSS4	B5R4.R	VMADE	10030.1332	insert Rf inverses	3	
30	LSS4	B5R4.B	VMADE	10020.6632	insert Rf inverses	3	

# LIST OF ALL NONCONFORMITIES (2/3)

31	LSS4	D5R4.B	VMAAB	10056.0122	distance recouvrement nulle	2
32	LSS4	D5R4.B	VMBGA	10063.3122	ressort hors logement, leger flambage interne des doigts	1
33	LSS4	D5R4.R	VMAAF	10063.1472	ressort hors logement	2
34	LSS4	E5R4.B	VMAAE	10084.9402	ressort hors logement, leger flambage interne des doigts	1
35	LSS4	E5R4.R	VMAAF	10084.9402	ressort de traction hors logement, doigts deforms	2
36	LSS4	E5R4.R	VMANC	10114.1402	doigts RF formant cavite vers l'exterieur	1
37	LSS4	A7R4.B	VMAAB	10176.6962	Ressort hors logement, deformation, distance nulle	2
38	LSS5	A6L5.R	VM_XRPT1	13109.58	pas d'insert RF a l'interieur (pot romain)	3
39	LSS5	A6L5.R	VM_XRPT2	13115.58	pas d'insert RF a l'interieur (pot romain)	3
40	LSS5	A5L5.B	VMANC	13137.7346	inser Rf inverses	3
41	LSS5	A5L5.B	VMAAF	13148.3286	ressort hors logement, qq doigts deforms et coincés dans soufflet	2
42	LSS5	A5L5.B	VMACB	13154.3186	ressort hors logement	2
43	LSS5	B4L5.R	VM_XRPT1	13179.1	pas d'insert RF a l'interieur (pot romain)	3
44	LSS5	B4L5.R	VM_XRPT2	13180.33	pas d'insert RF a l'interieur (pot romain)	3
45	LSS5	A4L5.C	VMBGG	13208.5416	distance recouvrement nulle	2
46	LSS5	A4L5.C	VMBGG	13221.1416	distance recouvrement nulle	2
47	LSS5	A1L5.X	VBX	1330811.16	absence de ressort, distance recouvrement nulle	2
48	LSS5	A4R5.C	VMBGA	13431.0416	absence ressort, qq doigts Rf coincés dans ondulations	2
49	LSS5	A4R5.C	VMBGA	13443.6416	absence ressort, qq doigts Rf coincés dans ondulations	2
50	LSS5	A4R5.C	VMEGB	13468.8416	vide !	1
51	LSS5	B4R5.B	VM_XRPT1	13478.52	pas d'insert RF a l'interieur (pot romain)	3
52	LSS5	B4R5.B	VM_XRPT2	13479	pas d'insert RF a l'interieur (pot romain)	3
53	LSS5	A5R5.B	VMAAF	13510.2546	distance recouvrement nulle	2
54	LSS5	A5R5.B	VMACC	13521.4656	ressort hors logement, leger flambage interne des doigts	1
55	LSS5	A6R5.B	VM_XRPT1	13544.21	pas d'insert RF a l'interieur (pot romain)	3
56	LSS5	A6R5.B	VM_XRPT2	13549.28	pas d'insert RF a l'interieur (pot romain)	3
57	LSS6	C5L6.R	VMAAB	16442.47	flambage externe	2
58	LSS6	C5L6.R	VMAAF	16426.357	reduction ouverture	1
59	LSS6	C5L6.R	VMAND	16449.77	1 doigt Rf hors logement	3
60	LSS6	A5L6.B	VMADE	16485.494	insert Rf inverses	3

# LIST OF ALL NONCONFORMITIES (3/3)

61	LSS6	A4L6.B	VMZAN	16538.022	doigts bloques, leger flambage interne des doigts	1
62	LSS6	A4L6.R	VMTAB	16516.662	flambage externe des doigts	1
63	LSS6	A4L6.R	VMZAM	16542.266	distance recouvrement nulle	2
64	LSS6	A4L6.R	VMZAD	16558.383	distance recouvrement nulle	2
65	LSS6	IP6.R	VMAAF	16617.527	correction alignement	3
66	LSS6	IP6.R	VMSDU	16624.827	vide !	1
67	LSS6	IP6.R	VMSDO	16698.477	vide !	1
68	LSS6	IP6.R	VMZAK	16707.212	Ressort hors logement, deformation extremite doigt	2
69	LSS6	IP6.B	VMSDO	16624.827	vide !	1
70	LSS6	IP6.B	VMSDR	16664.107	absence de contact	1
71	LSS6	IP6.B	VMSDU	16698.477	vide !	1
72	LSS6	IP6.B	VMAAB	16708.247	Ressort hors logement, deformation extremite doigt	2
73	LSS6	A4R6.B	VMZAD	16764.871	correction alignement	3
74	LSS6	A4R6.B	VMTAB	16813.792	doigts coincés entraînant un flambage externe	1
75	LSS6	A4R6.R	VMZAN	16776.314	ressort hors logement	2
76	LSS6	A4R6.R	VMAAB	16804.472	ressort hors logement	2
77	LSS6	A5R6.B	VMAND	16837.82	extremite doigts Rf deforme	3
78	LSS6	A5R6.B	VMANC	16866.17	ressort hors logement	2
79	LSS6	C5R6.B	VMAAF	16884.847	plusieurs doigts non tenu par ressort, leger flambage interne	2
80	LSS6	E5R6.R	VMACD	16927.887	ressort hors logement	2
81	LSS7	IP7.R	VMTQB	19997.9624	flambage plusieurs doigts	1
82	LSS7	IP7.R	VMAND	20035.2624	Insert inverses sur VAGLC	3
83	LSS7	A5R7.B	VMTQB	20089.1584	ressort hors logement	2
84	LSS7	B5R7.B	VMGLA	20115.0334	absence de ressort - recouvrement nul	2
85	LSS7	A7R7.B	VMACC	20251.9914	ressort hors logement - doigts Rf dans ondulations soufflet	1
86	LSS7	A7R7.R	VMACD	20251.9914	ressort hors logement - doigts Rf dans ondulations soufflet - absence contact	1
87	LSS8	A6L8.B	VMACC	23137.5178	distance recouvrement nulle	2
88	LSS8	B1L8.X	VMAAA	23246.0048	distance recouvrement nulle	2
89	LSS8	B1R8.X	VMAAA	23384.4008	distance recouvrement nulle	2
90	LSS8	A6R8.B	VMANC	23494.8128	absence totale de contact, flambage externe	1
91	LSS8	A6R8.R	VMSIN	23507.8508	ressort hors logement	2
92	LSS8	A6R8.R	VMACC	23552.0568	ressort hors logement, doigts deformes	2



# RECENT ISSUES OBSERVED WITH RF CONTACTS IN SPS

- ◆ Concerns RF power transmission lines in the SPS BA3 Philips plant in 2012
- ◆ There are 68 RF power amplifiers in total, 200 MHz, 35 kW, CW and 17 output power transmission lines are dismantled / year for maintenance
- ◆ No problem during 35 years but this year some pbs were encountered for the first time with the innerspring contact clamp which ensures the continuity of the inner line of the RF transmission line
- ◆ The pb was traced back to a bad procedure, using in some cases springs which were too long. As it was too difficult to insert it in the inner line, the mechanist decided to shorten the RF spring contact. The bad RF contact had then important consequences, as the clamp was then destroyed => This is another example that if everything is mounted normally there is no problem but if the RF contact is too poor, then it can have dramatic effects



## GUIDELINES FOR (SLIDING) RF FINGERS (1/4)

- ◆ **Material to be used for the RF fingers => CuBe (grade very important in case of bake-out => C17410): good conductor, good adhesion of coatings, weldability by e- beam, good formability properties, low magnetic permeability (low content of Ni, but contains Co – small enough amount for RP, but more than Be...), higher elasticity than Cu alone, etc.**
- ◆ **CuBe is a good conductor but still too high surface impedance => Coating needed to increase surface conductivity + reduce contact resistance + avoid cold welding**
- ◆ **No cold welding => 2 solutions**
  - **Put a diffusion barrier between the 2 metals (oxide layer) => Bad for the electrical contact**
  - **Choose metals with lowest solubility => Solution adopted and the best materials' pair is Au-Rh (best enemies => Almost no solubility). Ag-Rh is quite similar**

## GUIDELINES FOR (SLIDING) RF FINGERS (2/4)

### ◆ Contact resistance measurements

- With a plating of the CuBe RF finger in Au and a plating of the base material (Cu) in Rh, the resistance was measured to be  $\sim 3 \text{ m}\Omega$  for 1 RF finger (i.e.  $\sim 0.1 \text{ m}\Omega$  for 1 PIM)  $\Rightarrow$  It was measured to be  $\sim 35 \text{ m}\Omega$  for the baseline Ag / SS contacts (i.e.  $\sim 1.2 \text{ m}\Omega$  for 1 PIM)
- The use of Ag instead of Au led to  $\sim 2 \text{ m}\Omega$  but Au was chosen for the PIMs for the cold welding reason
- Contact surface on the insert  $\Rightarrow$  Electro-polished before putting the Rh coating

### ◆ Bake-out for the collimators (250°C)

- Au cannot be used because of the bake-out at 250°C (due to the diffusion of the Cu into Au and then the Au layer disappears). The same problem happens with Ag but at a higher temperature  $\Rightarrow$  Au was replaced by Ag for the collimators

## GUIDELINES FOR (SLIDING) RF FINGERS (3/4)

- ◆ **Bake-out for the MKI injection kickers ( $\sim 350^{\circ}\text{C}$ )**
  - SS (instead on CuBe, but still Au plated) is used for the MKI RF fingers because of the bake-out at  $\sim 350^{\circ}\text{C}$ , which would lead with CuBe to a very small residual elasticity of  $\sim 20\%$  only (see next slide)
- ◆ **Finally, any gap should be avoided as it can be fatal (depends on real geometry) => Try and design a robust mechanical design to keep all the RF fingers in contact**

# GUIDELINES FOR (SLIDING) RF FINGERS (4/4)

Stress relaxation resistance for high conductivity alloy (at 75% stress)

## ◆ How to read it?

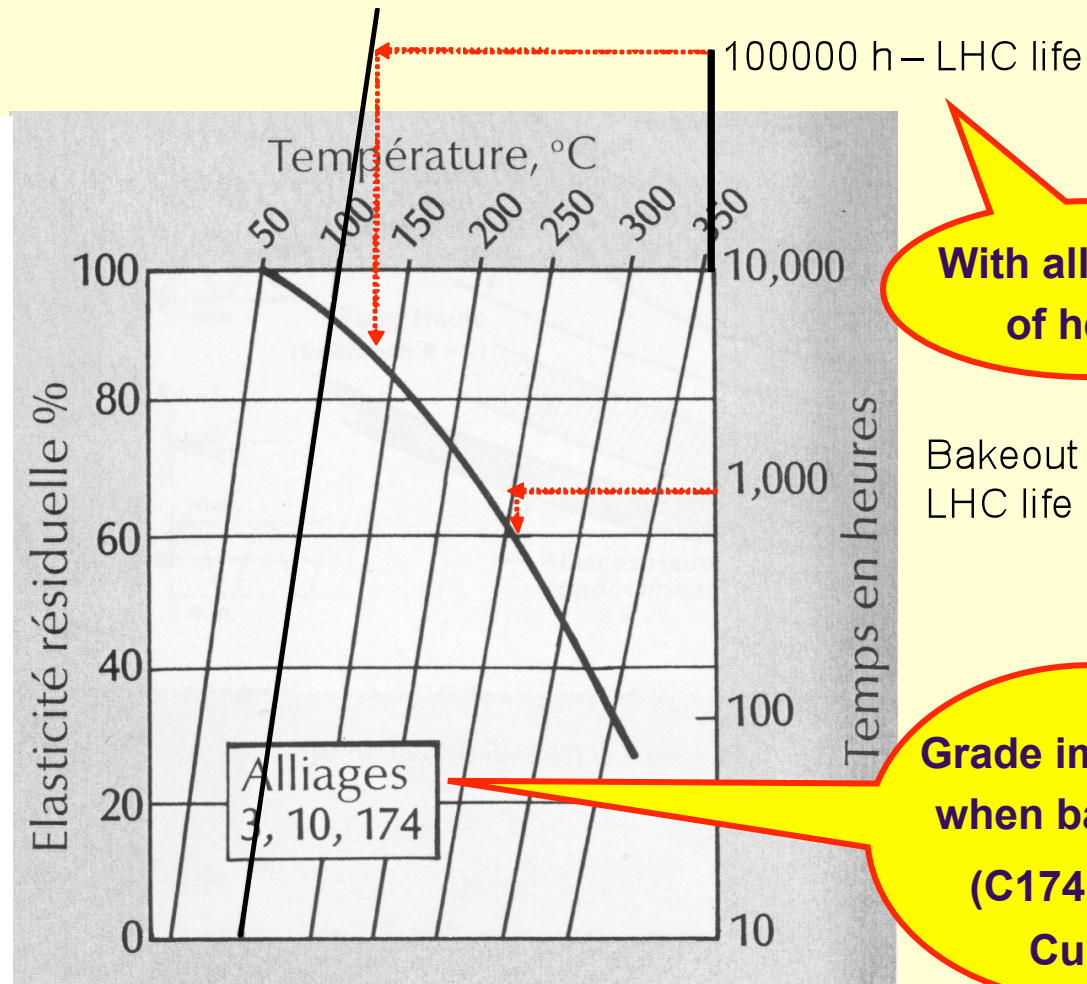
1) Choose Temp line

=> Ex: 250°C (bake-out)

2) Then choose # hours of bake-out => Ex: 1000 h

3) Go vertically from this point to the curve

=> Gives the residual elasticity in %: 60% here (goal is to keep it as high as possible)



With all sources of heating

Bakeout time in LHC life

Grade important when bake-out!  
(C17410 for CuBe)

# FERRITE: SEVERAL TYPES, CRITERIA & GUIDELINES (1/4)

## ◆ Location of the ferrite (assuming known EM properties)

- EM simulations and put the ferrite at (close to) the maximum of the magnetic field of the mode to be damped (at the metallic wall)
- Should not be seen directly by the beam (if possible)...

## ◆ Penetration depth

$$\delta ( f ) = \frac{c}{2 \pi f} \times \frac{1}{\operatorname{Re} \left[ \sqrt{1 - \varepsilon_{rc} ( f ) \mu_{rc} ( f )} \right]}$$

with

$f$

frequency

$c$

speed of light

$$\varepsilon_{rc} ( f ) = \varepsilon' - j \varepsilon'' = \varepsilon' ( 1 - j \tan \delta_{\varepsilon} )$$

relative complex permittivity

$$\mu_{rc} ( f ) = \mu' - j \mu'' = \mu' ( 1 - j \tan \delta_{\mu} )$$

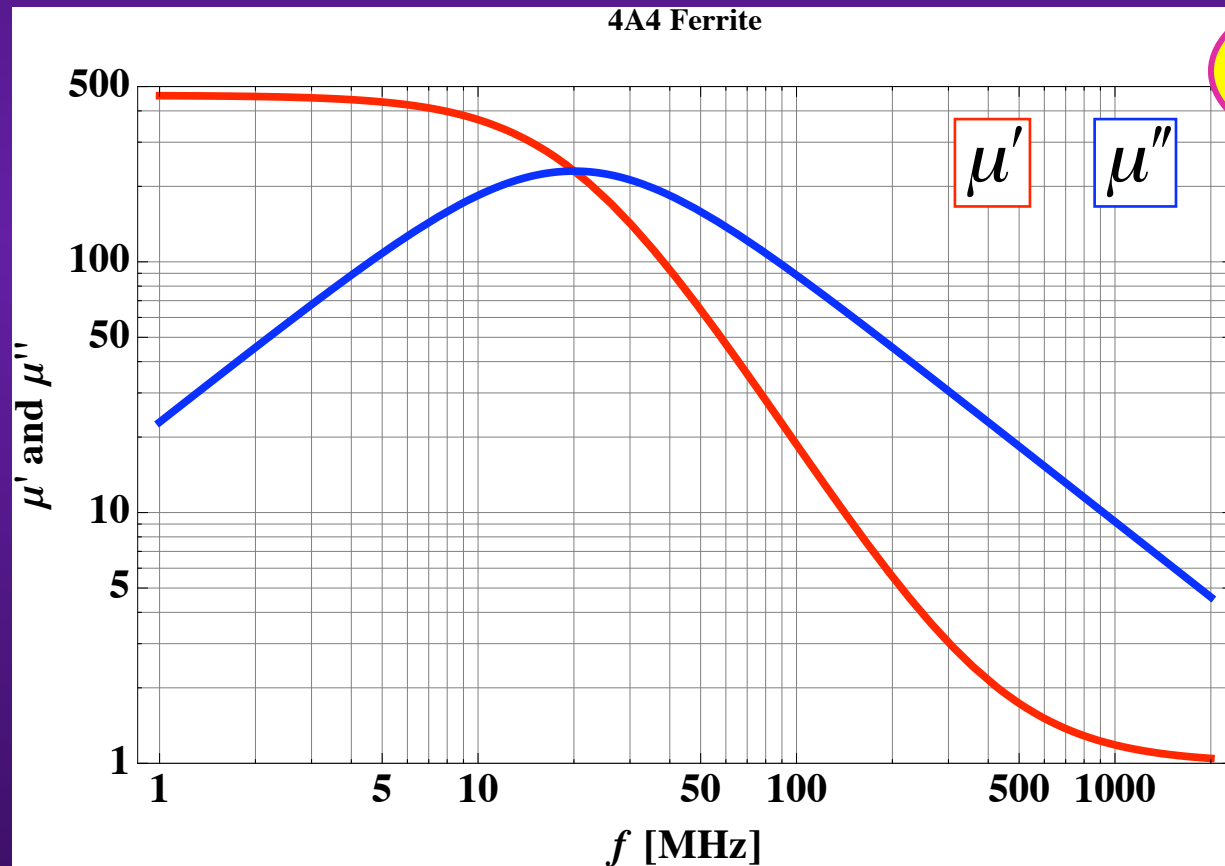
relative complex permeability

# FERRITE: SEVERAL TYPES, CRITERIA & GUIDELINES (2/4)

- Case of the 4A4 ferrite

$$\mu_{rc}(f) \approx 1 + \frac{460}{1 + j \frac{f}{2 \times 10^7}}$$

$$\varepsilon_{rc}(f) \approx \varepsilon'$$



The  $\varepsilon''$  is usually small and can be neglected

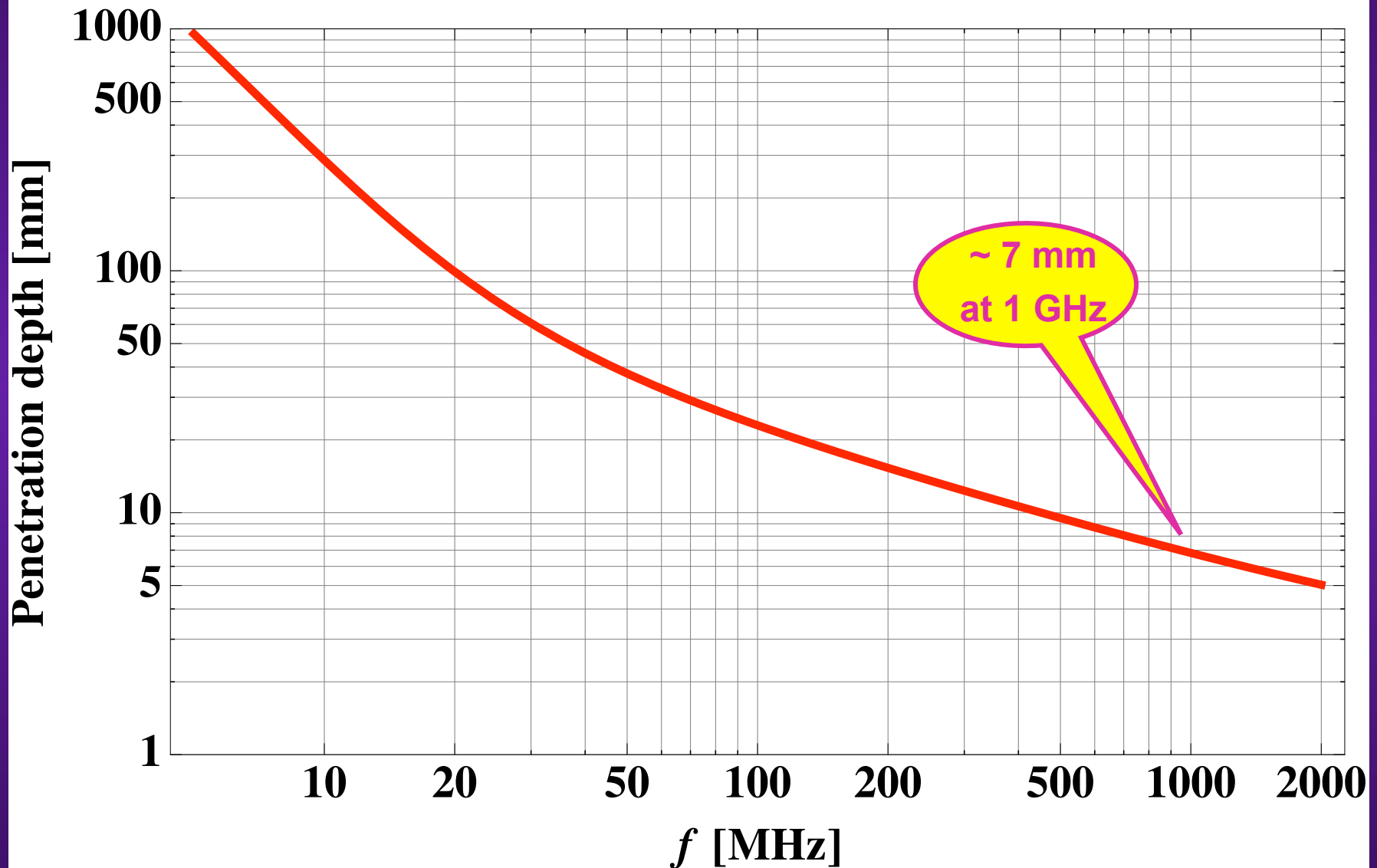
$$\varepsilon' \approx 12$$

$$\sigma \approx 10^{-6} \text{ S/m}$$

$\varepsilon_0$  vacuum permittivity

# FERRITE: SEVERAL TYPES, CRITERIA & GUIDELINES (3/4)

4A4 Ferrite





# FERRITE: SEVERAL TYPES, CRITERIA & GUIDELINES (4/4)

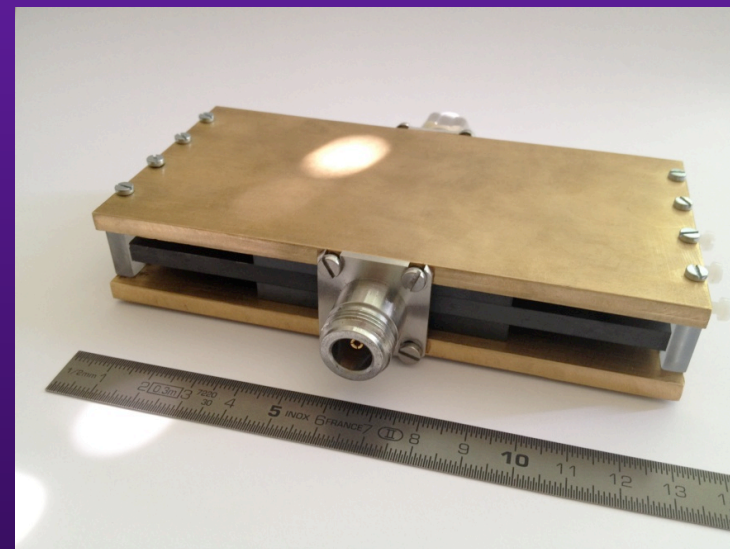
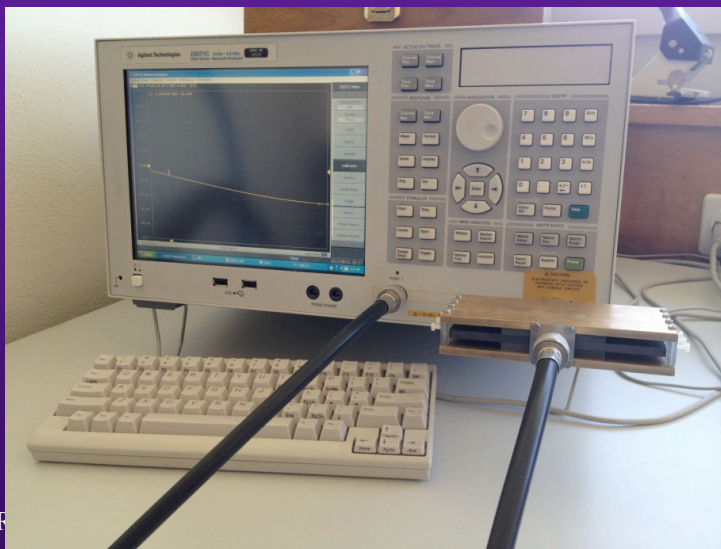
- ◆ To damp a mode at a frequency  $f$ , a ferrite's thickness equal to the penetration depth at frequency  $f$  is an upper limit => It is enough to have less, say (as a 1<sup>st</sup> guideline, but it should be confirmed by simulation for the particular case under study):

$$\text{Ferrite thickness} \approx \text{penetration depth} / 2$$

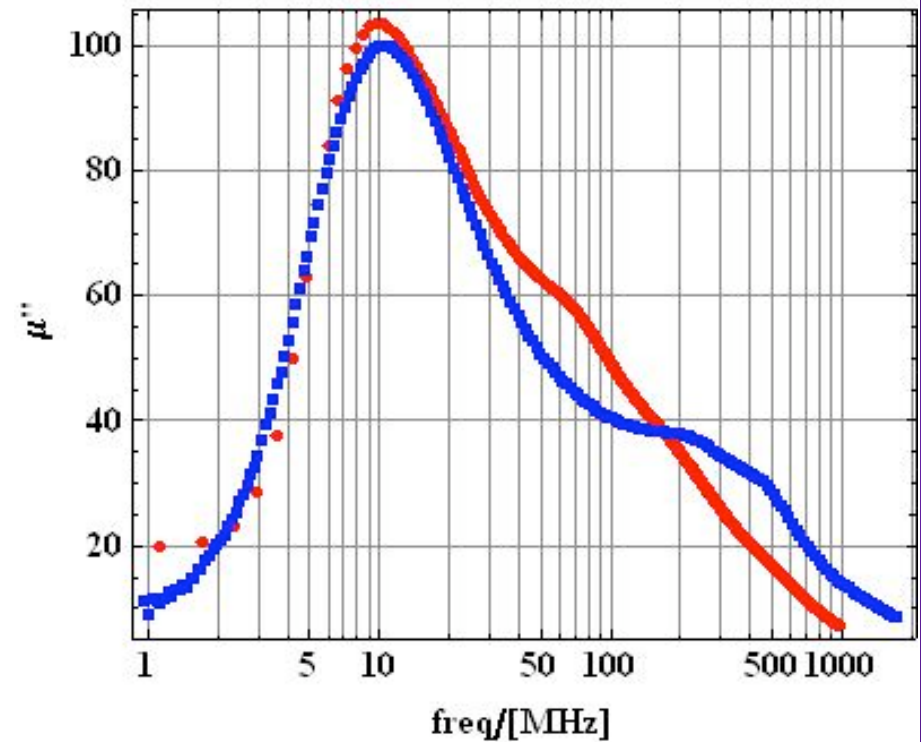
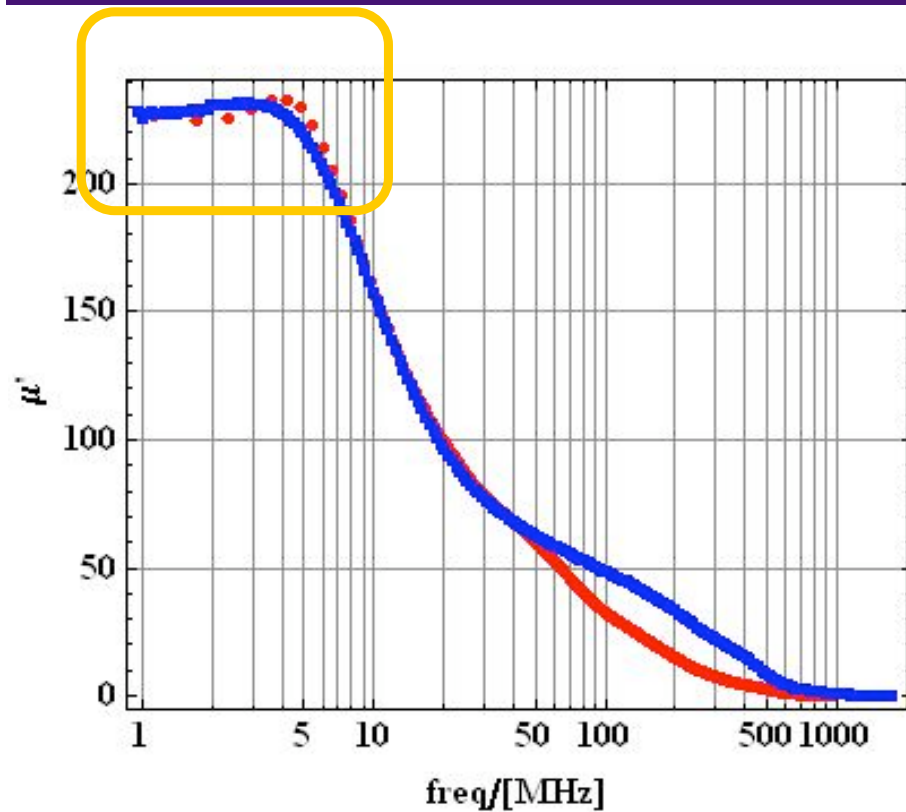
- ◆ Example with the previous (fitted) 4A4 ferrite: if one wants to damp a mode at 1 GHz, a thickness of ~ 3-4 mm is OK
- ◆ Remarks:
  - Depending on the frequency, one has to optimize the ferrite to be used
  - A lower limit for the ferrite's thickness is given by mechanical considerations => Should be > few mm for ferrite's tiles. For plasma sprayed ferrite (under study to improve heat conduction, see later), the thickness is dictated by the technology (maximum of few hundreds  $\mu\text{m}$ )

# MEASUREMENTS OF THE FERRITE EM PROPERTIES (1/2)

- ◆ **Nominated “ferrite responsible persons” at CERN: Fritz Caspers and Christine Vollinger**
- ◆ **EM measurements of the TT2-111R ferrite**
  - This ferrite is readily available in tiles of 6 cm x 6 cm and 5 mm thickness
  - Material samples are “wrapped” around an inner conductor
  - This allows a non-destructive (transmission & reflection) meas.
  - Without any machining of the ferrite => It is much simpler to machine metal than ceramics with adequate accuracy



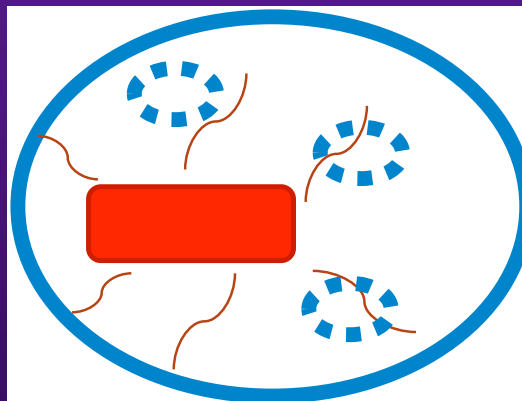
# MEASUREMENTS OF THE FERRITE EM PROPERTIES (2/2)



Red = Measurement in SH-sample holder  
Blue = Measurement provided by TT

# FIG. OF MERIT & GUIDELINES FOR FERRITE HEATING (1/6)

- ◆ **Goal: Determine figures of merit for the maximum RF induced power on ferrite before  $T_{\text{Curie}}$  is reached**
- ◆ **Several assumptions**
  - 1) Steady-state regime and uniform ferrite temperature distribution (regardless of actual RF power deposition)
  - 2) Ferrite tile is of arbitrary cross section
  - 3) Ferrite radiates from all sides with equal emissivity (0.8)
  - 4) Completely surrounding heat sink & no intermediate components between ferrite & sink (ferrite view factor equal to 1)
  - 5) 2D simplification of ferrite tile => Infinitely long geometry (no end effects)
  - 6) Heat sink with uniform emissivity and temperature



# FIG. OF MERIT & GUIDELINES FOR FERRITE HEATING (2/6)

CASE:

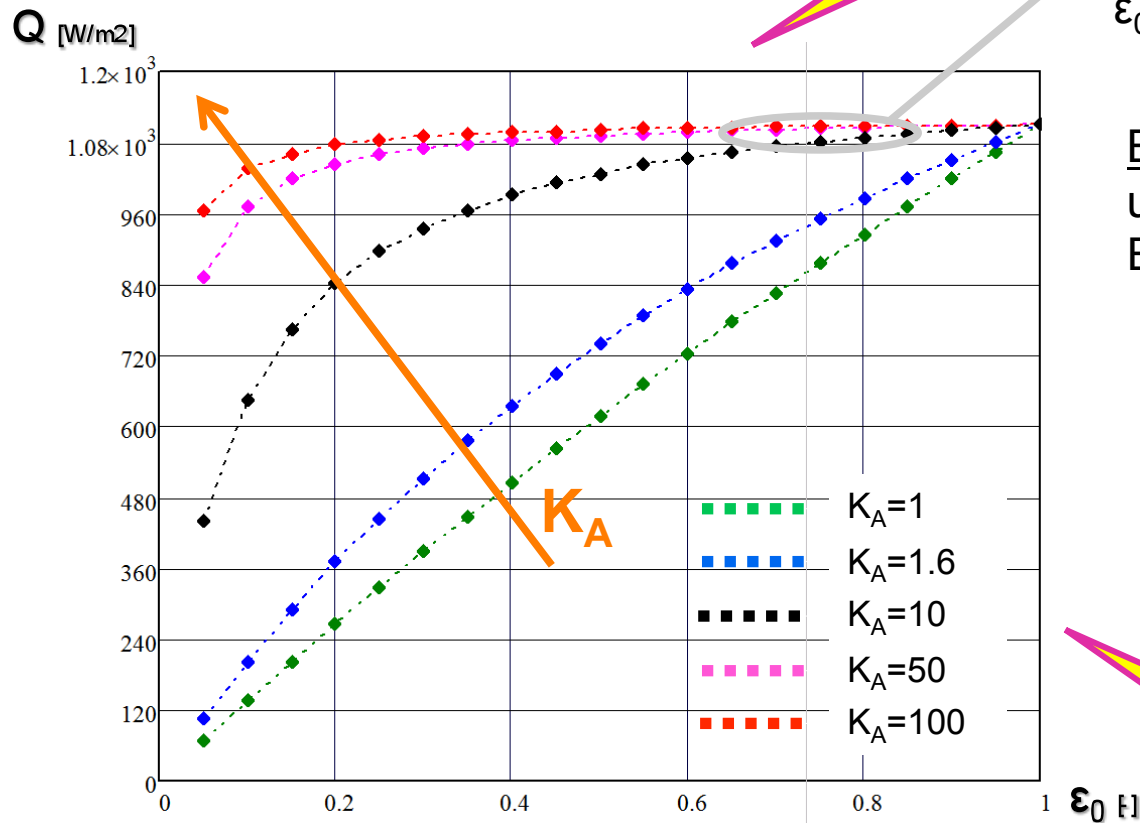
$$\epsilon_{\text{FERRITE}} = 0.8$$

$$T_{\text{CURIE}} = 150^\circ\text{C}$$

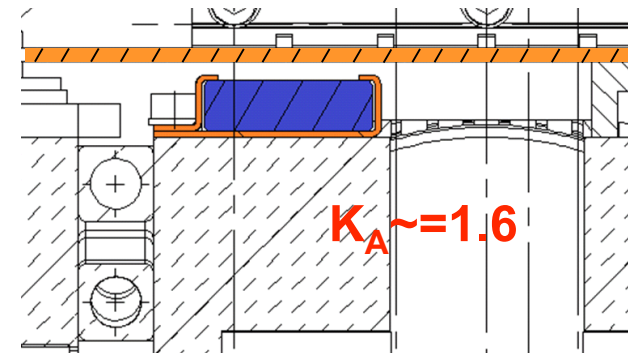
$$T_0 = 22^\circ\text{C} \text{ (i.e. cooled heat sink)}$$

Radiated heat /  
ferrite surface unit

If  $K_A$  is high  $\rightarrow$  no need for very high  $\epsilon_0$



But ferrite needs to be held, i.e.  $K_A$  is usually near to one.  
E.g. TCTP collimator:



$K_A$  = Surface of the  
sink / surface of the  
ferrite

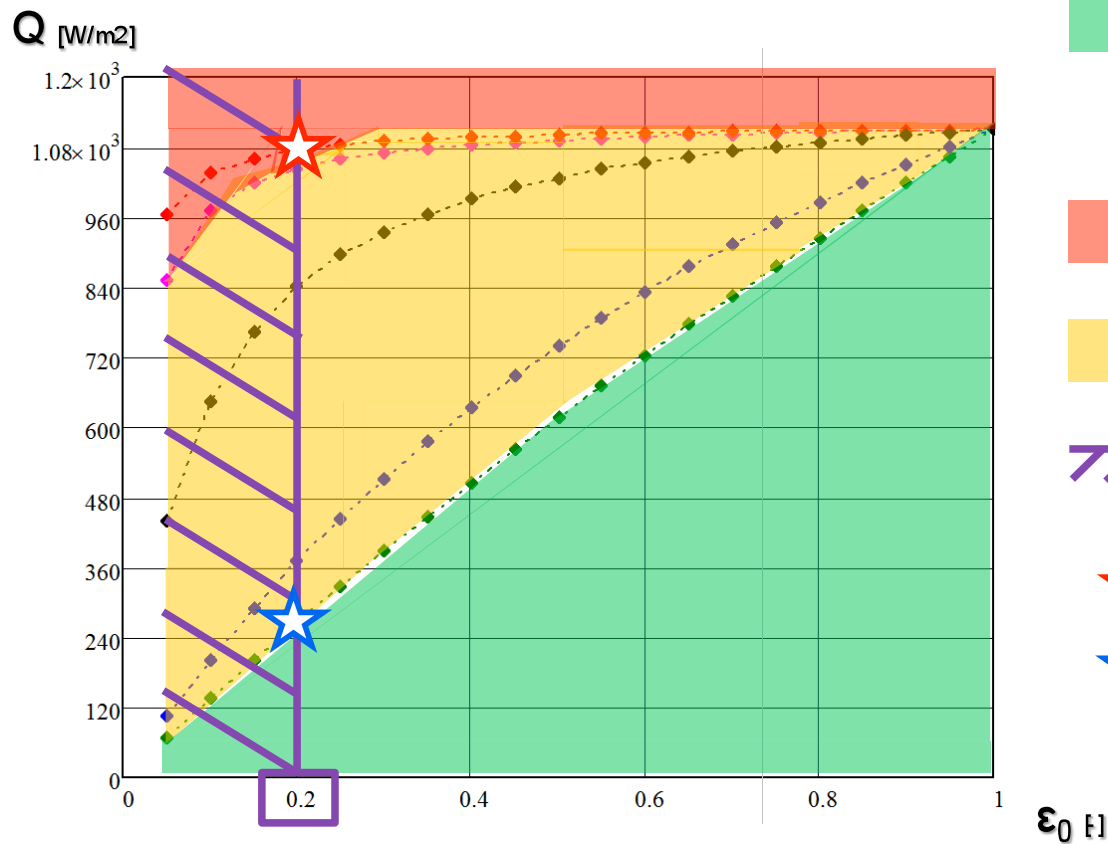
# FIG. OF MERIT & GUIDELINES FOR FERRITE HEATING (3/6)

CASE:

$$\epsilon_{\text{FERRITE}} = 0.8$$

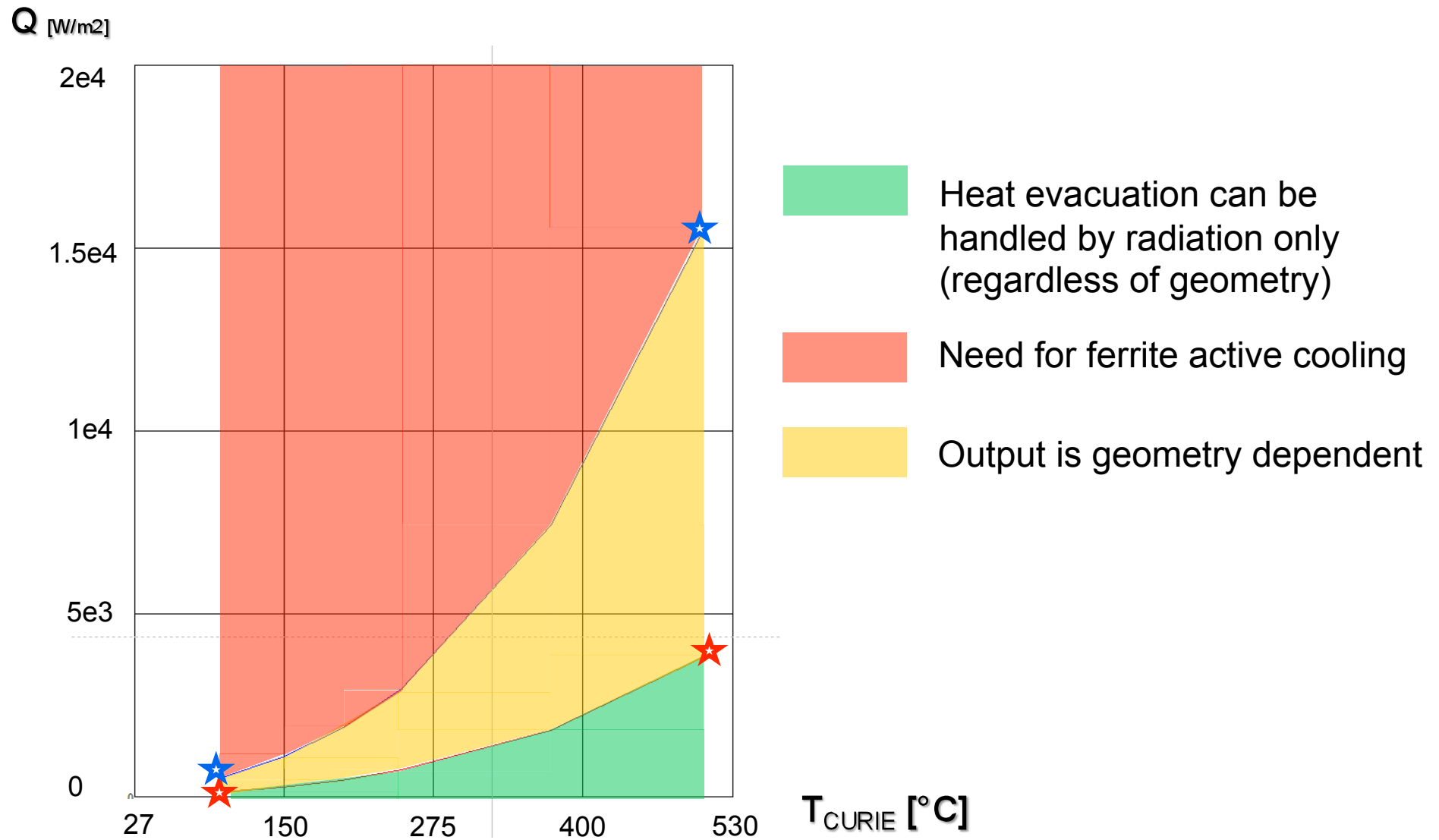
$$T_{\text{CURIE}} = 150^{\circ}\text{C}$$

$$T_0 = 22^{\circ}\text{C} \text{ (i.e. cooled heat sink)}$$



- Heat evacuation can be handled by radiation only (regardless of geometry)
- Need for ferrite active cooling
- Output is geometry dependent
- Critical design zone
- ★ High  $K_A$  point of interest
- ★ Low  $K_A$  point of interest

# FIG. OF MERIT & GUIDELINES FOR FERRITE HEATING (4/6)



# FIG. OF MERIT & GUIDELINES FOR FERRITE HEATING (5/6)

## ◆ How can we cool the ferrite if it becomes too hot?

- Try and improve the conduction from ferrite as most of the time only radiation is used (given the general brittleness of the ferrite we cannot apply big contact force/pressure)
- Plasma spray (for better conduction) => Collaboration with Aachen university (FritzC)

## ◆ Ferrite proposed for TCTP collimators

- TT2-111R (Trans-Tech) due to high Curie Temperature of  $\sim 375^{\circ}\text{C}$
- Best solution for the support material? Several cases studied: pure copper OFE, SS, copper OFE with CrO coating. The latter is the best choice from the thermal point of view, temperature on ferrite decreased by 25-30% with respect to SS (this reduction could be  $\sim 40\%$  when the upper screen is also coated with CrO). But, is the chrome coating on copper a potential UFO generator (as black chrome presents a dusty surface, i.e. risk of particles detachment)?

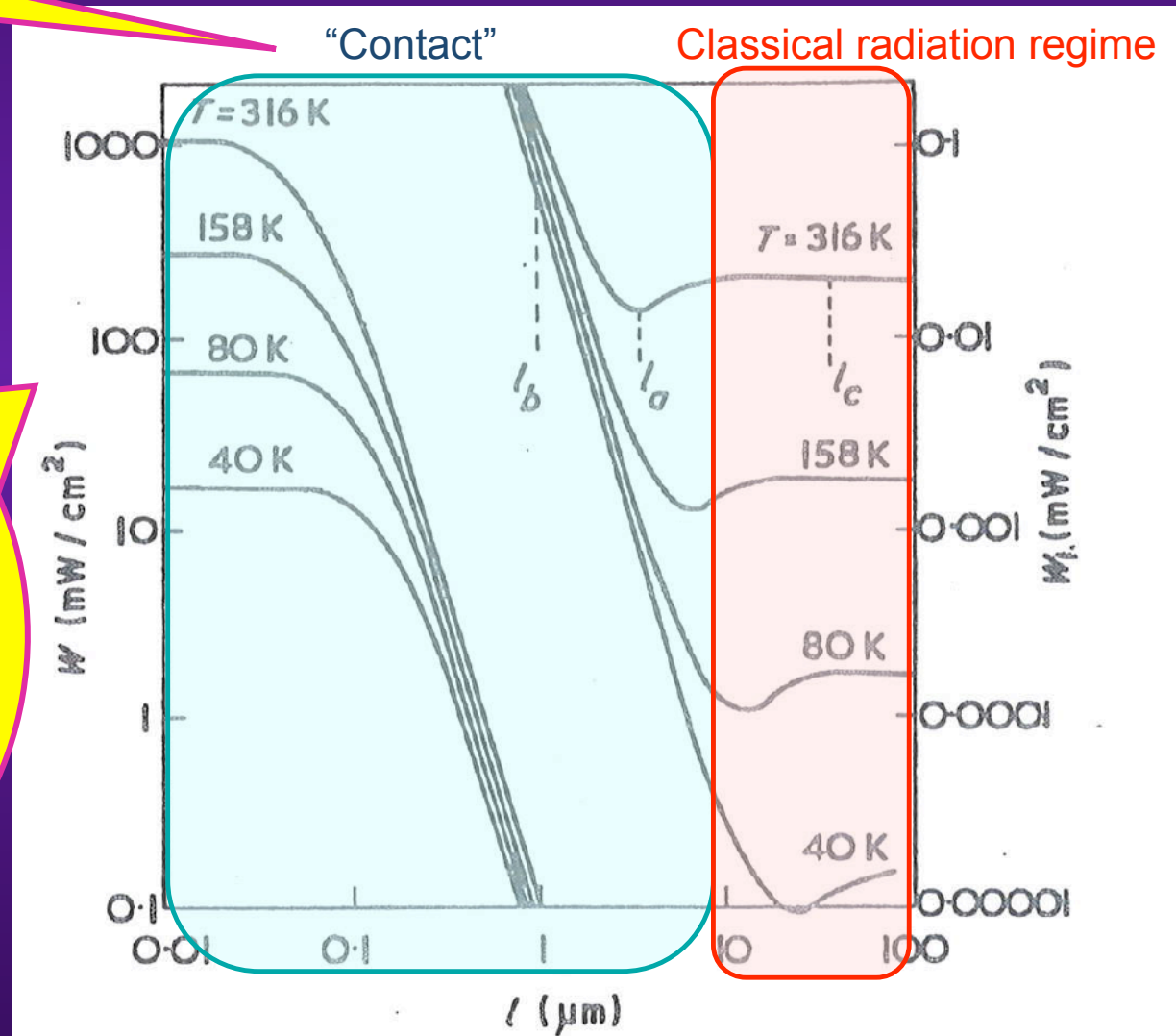


# FIG. OF MERIT & GUIDELINES FOR FERRITE HEATING (6/6)

## Near-field effects

Infra-red tunneling region

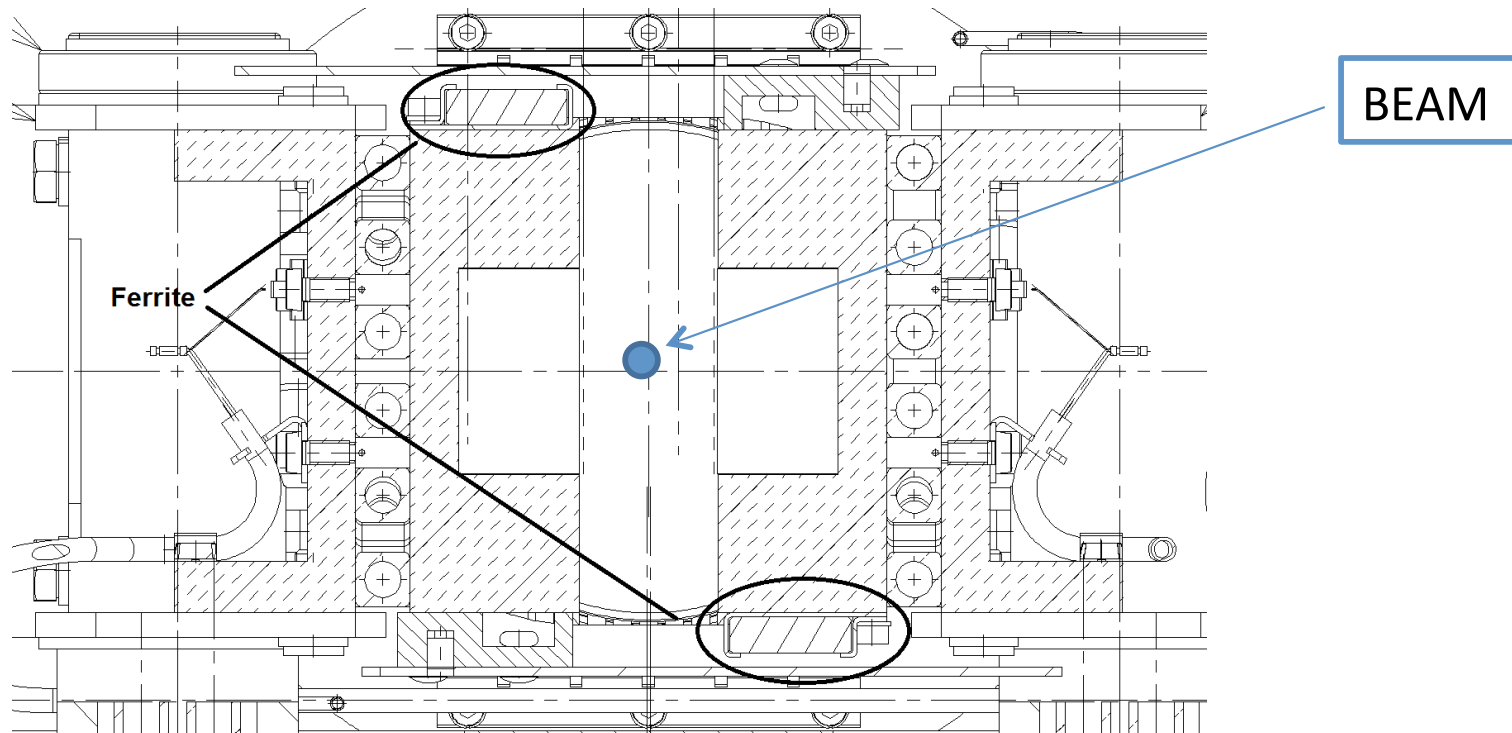
Total radiative transfer between 2 // surfaces spaced by  $l$   
=> Smooth transition between radiation and contact regimes.  
Applying a mechanical pressure, the gap is reduced



# MEAS. OF THE FERRITE VACUUM PROPERTIES (1/4)

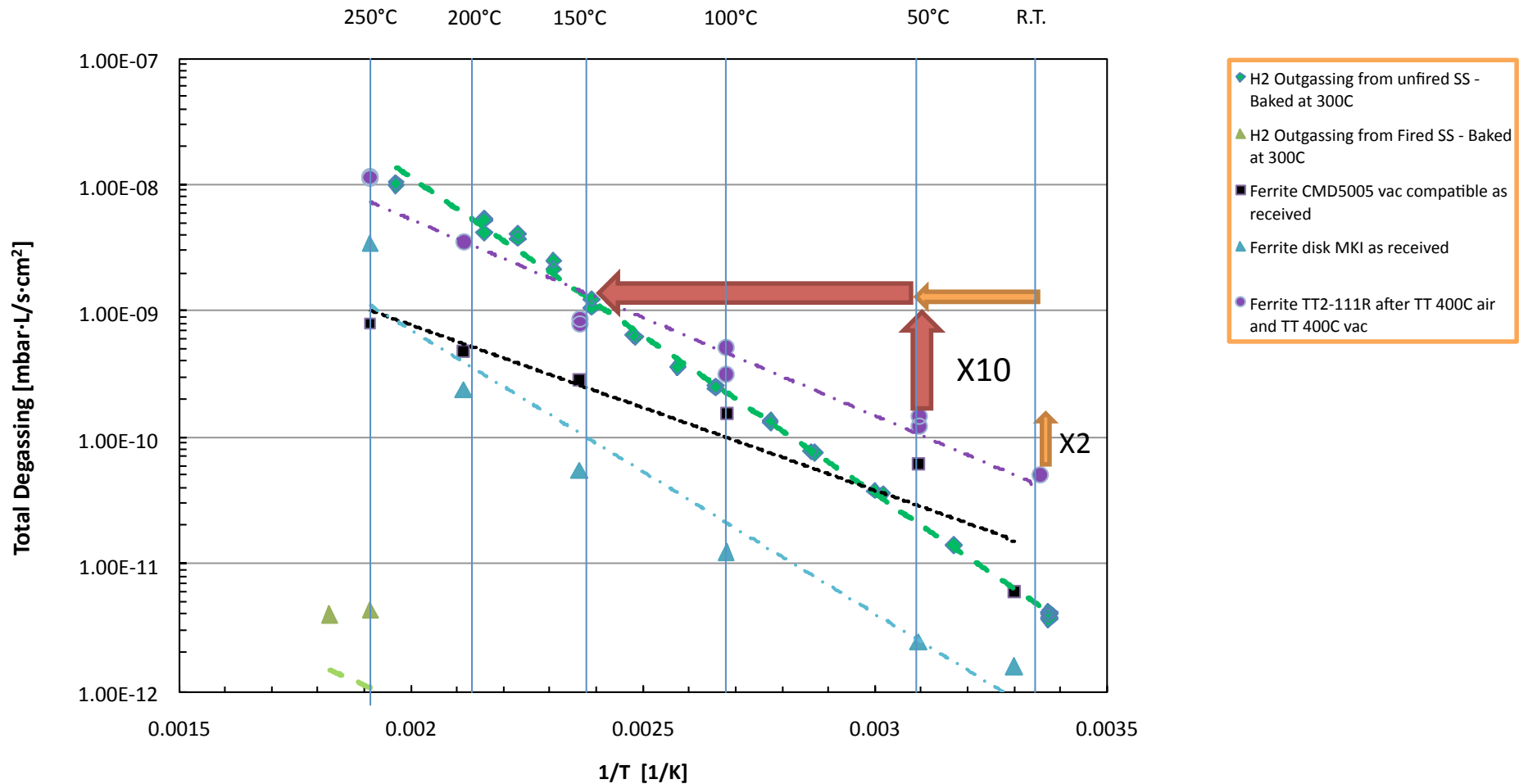
- ◆ The ferrite has to be compatible with UHV => Vacuum approval
- ◆ Ex. of vacuum (outgassing) measurements of the TT2-111R ferrite

Cross cut of a TCTP collimator:



**Total surface of ferrite per collimator = 1600 cm<sup>2</sup>**

# MEAS. OF THE FERRITE VACUUM PROPERTIES (2/4)



➔ Factor 10 gain in outgassing rate for 100°C temperature increase

## MEAS. OF THE FERRITE VACUUM PROPERTIES (3/4)

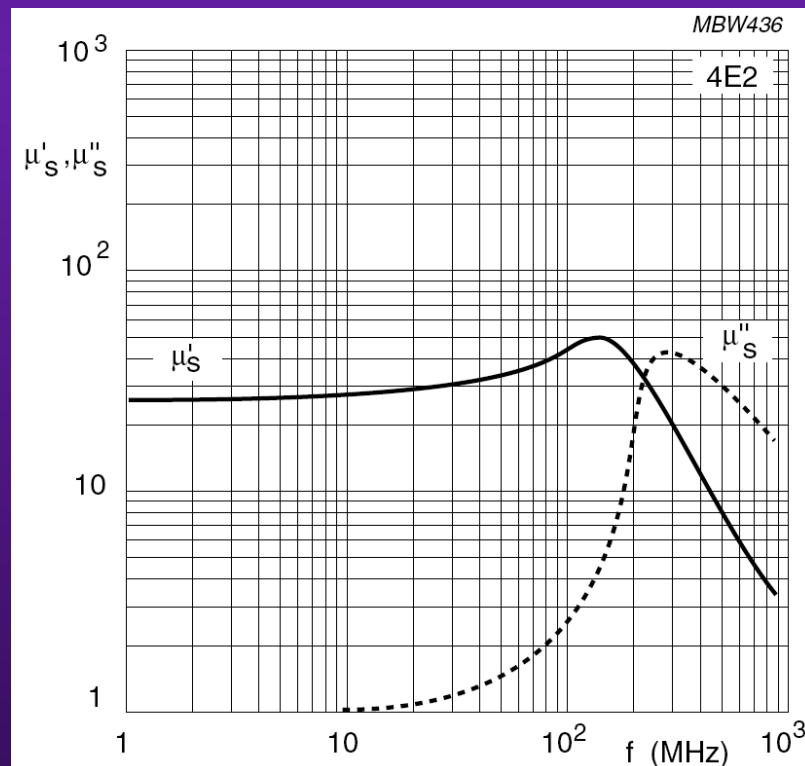
- ◆ **Scaling this to 1 TCTP collimator, the outgassed flow is close to the LHC vacuum specification limit of  $10^{-7}$  mbar l / s**
- ◆ **RGA (Residual Gas Analyzer) analysis shows no contamination**
- ◆ **The present solution does not present any safety margin in order to remain within the LHC vacuum specification should the ferrite temperature increase**

**=> VSC proposal: Vacuum test of ferrite with increased thermal treatment temperature (results should not be available before next year)**

**Very serious finding! Would have thought to be fine due to past experience**

## MEAS. OF THE FERRITE VACUUM PROPERTIES (4/4)

- ◆ TT2-111R ferrite interesting due to its high Curie temperature (~ 375°C) but the vacuum outgassing studies still need to be finalized
- ◆ Another ferrite with a high Curie temperature (> 400°C) was recently found (4E2 from Ferroxcube) => Some samples are being ordered to perform some EM and outgassing measurements



# PROS & CONS OF RF FINGERS AND FERRITE (1/2)

## RF FINGERS

- ◆ Avoid the changes of geometry and therefore the creation of (big) impedances
  - ◆ Optimization of the material of the RF fingers and the insert (contact resistance, cold welding, etc.)
  - ◆ Should not restrict the machine aperture (should not fall inside, buckling, etc.)
  - ◆ Should not go far away from the insert and create gaps (funneling, spring, fixed at both ends, etc.)
- => Biggest worry: assembly and mounting issues**

## FERRITE

- ◆ Here, there are already big impedances created and one wants to damp them
- ◆ Ferrite should not be seen directly from the beam (if possible)
- ◆ Position of the ferrite depends on the maximum of the magnetic field for the mode one wants to damp => **Detailed EM simulations needed**
- ◆ Ferrite's thickness depends on the penetration depth at the frequency of the mode one wants to damp
- ◆ The ferrite will absorb the remaining (normally much smaller) power => **Will heat. How to cool it?**

## PROS & CONS OF RF FINGERS AND FERRITE (2/2)

- ◆ **Due to some past issues with RF fingers (believed not to be related to impedances) the idea emerged to avoid RF fingers when possible and replace them by ferrite tiles (but there are not doing the same thing!) => For collimators only (transverse RF contacts)**
  - **Phase II collimators RF design was based on this idea**
    - **Potential issue with dust creation due to the movement**
    - **Potential issue with ferrite heating etc. => Studied in detail**
    - **Potential issue with chrome coating on copper (to reduce the ferrite's temperature) => Potential UFO generator (as black chrome presents a dusty surface)**
    - **Potential issue with vacuum => Ongoing studies**
  
- ◆ **Why not using ferrite for the PIMs?**
  - **Ferrite would not work due to the vicinity of magnets**
  - **The resonance cavity is so high that we don't need to care**

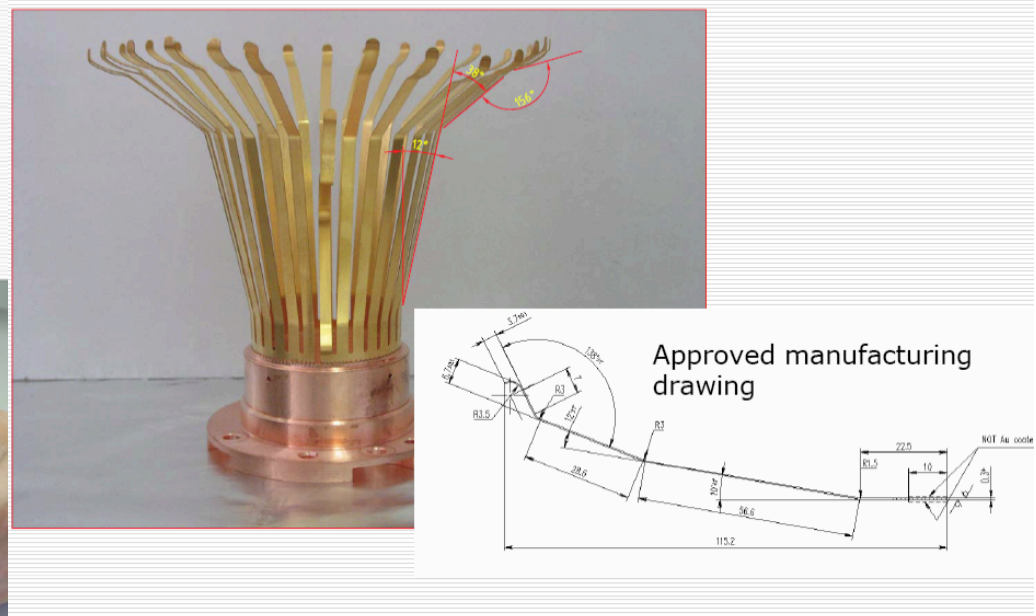
# WHAT WAS WRONG WITH THE PIMs IN THE COLD PART OF LHC (1/4)

- ◆ August 2007 => After warm-up of sector 7-8, a buckled PIM was discovered in interconnect QQBI.26.R7 with the radar (microwave beam pipe reflectometer)
- ◆ Was rapidly discovered to be due to a nonconformity during the manufacturing: bending angles out of tolerance. The angle should have been 12 deg (see also next slide)

QQBI.26R7 line V2



QQBI.26R7 V1 bending angles out of tolerance

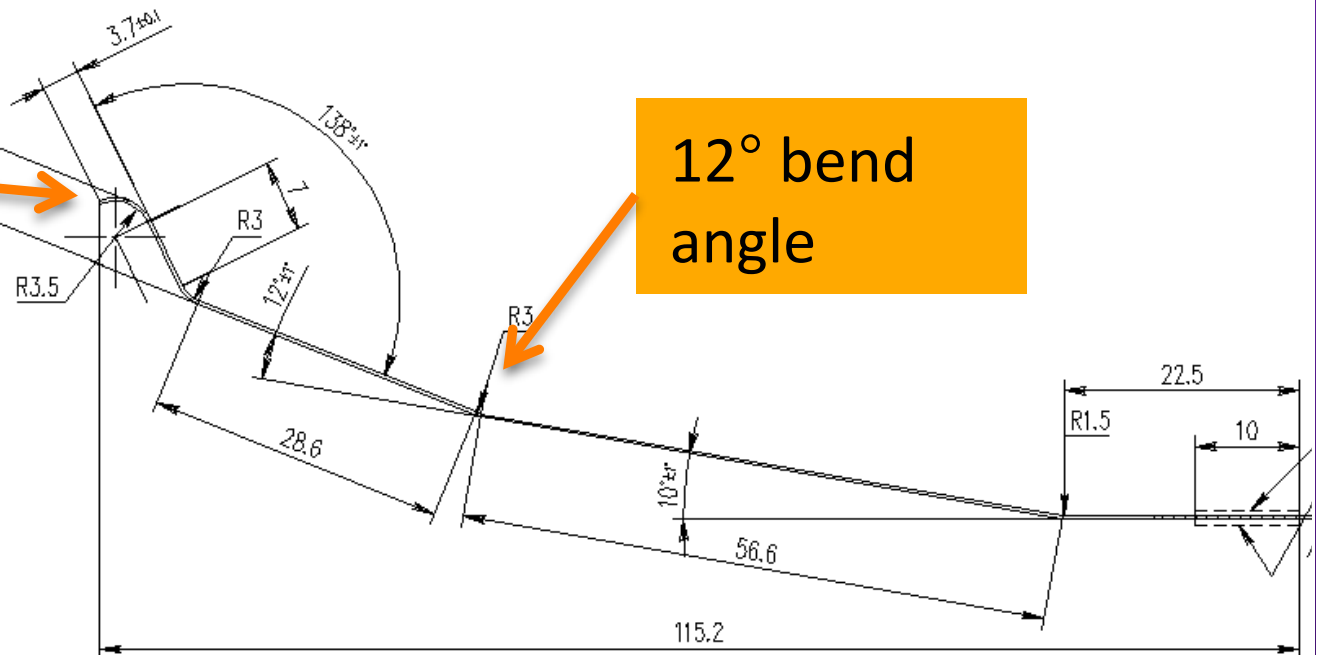




# WHAT WAS WRONG WITH THE PIMs IN THE COLD PART OF LHC (2/4)

- ◆ The specified electrical contact DC resistance of  $0.1 \text{ m}\Omega$  could not be reached (due to large surface roughness from Rhodium layer)
- ◆ To compensate it was decided to increase the contact force  
=> The bending angle was modified, which led to buckling issues

6.7mm finger height



$12^\circ$  bend angle

# WHAT WAS WRONG WITH THE PIMs IN THE COLD PART OF LHC (3/4)

## ◆ **Corrective actions taken**

- A tooling was designed to restore the correct geometry of the fingers => Back to conforming PIM (both angle and finger height at the tip)
- SSS moved by 2 mm to reduce the span of the QQBI => The stroke is smaller (we have gain 2 mm in the stroke)

## ◆ **Summary**

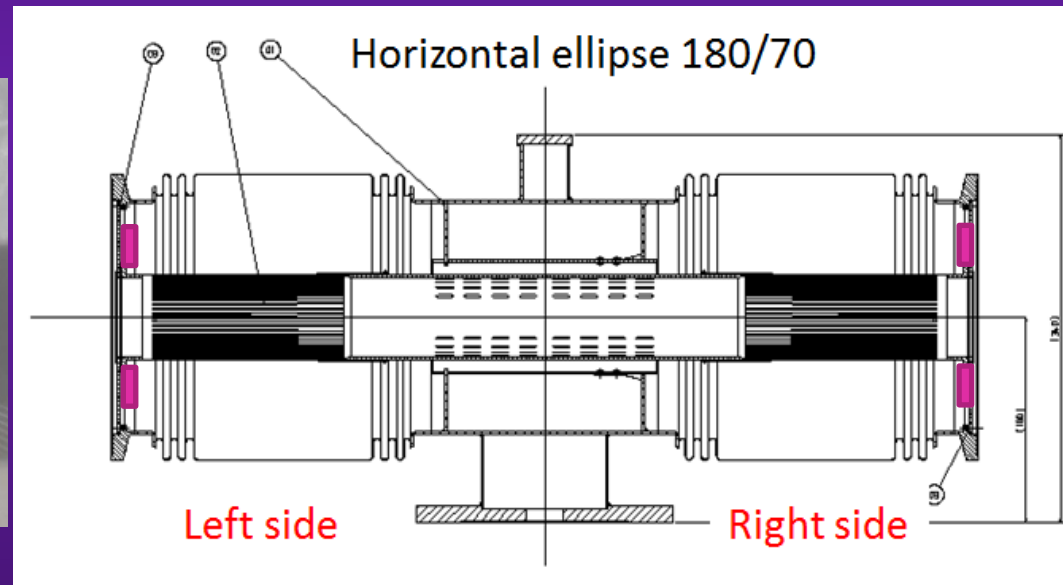
- The PIM pb was the too high (out of tolerance) electrical DC contact resistance which led to a mechanical pb (to reach the required contact resistance)
- It has been fully understood
- Nonconforming PIMs can be repaired
- Strategy for replacement has been defined and is applied

# WHAT WAS WRONG WITH THE PIMs IN THE COLD PART OF LHC (4/4)

- We still have this “Epee de Damocles” each time we will do a warm up we can have buckling
  - Warm-up to room temperature (or even  $> \sim 150$  K) can damage the PIMs => At each Technical Stop the warm-up is done below  $\sim 150$  K to avoid buckling
- Means of detection of damaged PIMS:
  - RF transmitter (the “ball”), pushed by a draft (2 m/s through the sector)
  - The radar (microwave beam pipe reflectometer)

## FOLLOW-UP OF VMTSA ISSUES IN 2011 (1/5)

- ◆ **Reminder: 10 modules (each of 2 bellows) in total in 2011. 8 bellows were found with defects. 2 modules removed for 2012**
- ◆ **Remark 1: No issues have been observed in 2012 (with shorter RF fingers + bent to reduce possible gap + ferrite tiles at both extremities => Final situation close to pictures below)!**



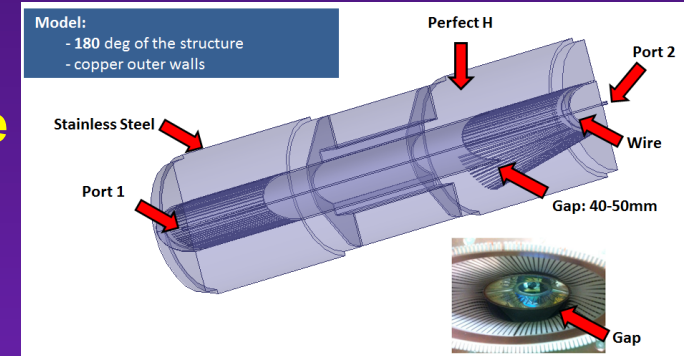
- ◆ **Remark 2: After LS1 there will be no VMTSA anymore as the 2-in-1 collimator will be removed (VMTSA used only for 2-beam coll.)**

## FOLLOW-UP OF VMTSA ISSUES IN 2011 (2/5)

- ◆ **Current interpretation of what happened to the VMTSA in 2011**
  - There must have been a heat source in the spring (as it melted whereas it has a higher melting point than the RF fingers)
  - We lost for any reason one or few contacts from RF fingers
  - The induced current which did not go to the 1<sup>st</sup> (main) contact (due to a gap) went to the 2<sup>nd</sup> contact (done by the spring) and the spring acted as a fuse
  - Due to the very small cross section of the spring and the too high current density it melted, broke and then released the bottom RF fingers due to gravity
  - A test revealed that  $\sim 1$  W in the spring was sufficient
  - What has been simulated is the validation of what happened after (i.e. with a gap)

## FOLLOW-UP OF VMTSA ISSUES IN 2011 (3/5)

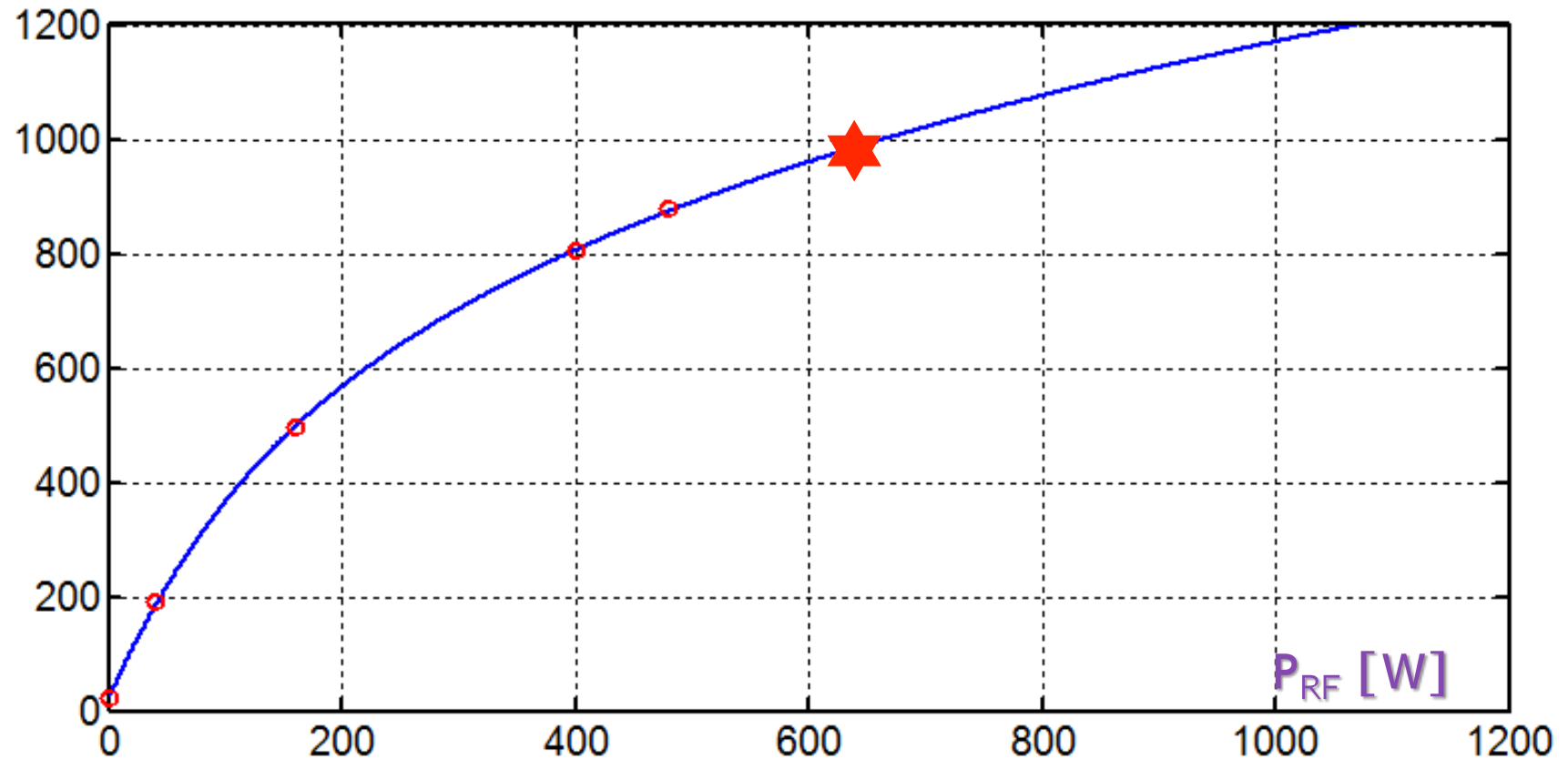
- ◆ EM simulations revealed that even a small gap between the RF fingers and the central insert could be fatal for the VMTSA operation => One should avoid “any” gap
- ◆ Simulated power deposited for the 2011 case
  - ~ 650 W for a gap of 40 mm
  - ~ 460 W for a gap of 50 mm
- ◆ Thermal evolution has been studied to try and answer to 2 questions: Is RF power deposition compatible with expected failure temperatures? Limit for power value?
- ◆ Reminder on melting temperatures
  - For 316L spring: ~ 1350°C
  - For CuBe RF fingers: 865°C / 1025°C (C17200 and C17410 respectively)



Surface loss density for the first eigenmode @ 279MHz

## FOLLOW-UP OF VMTSA ISSUES IN 2011 (4/5)

T [°C]

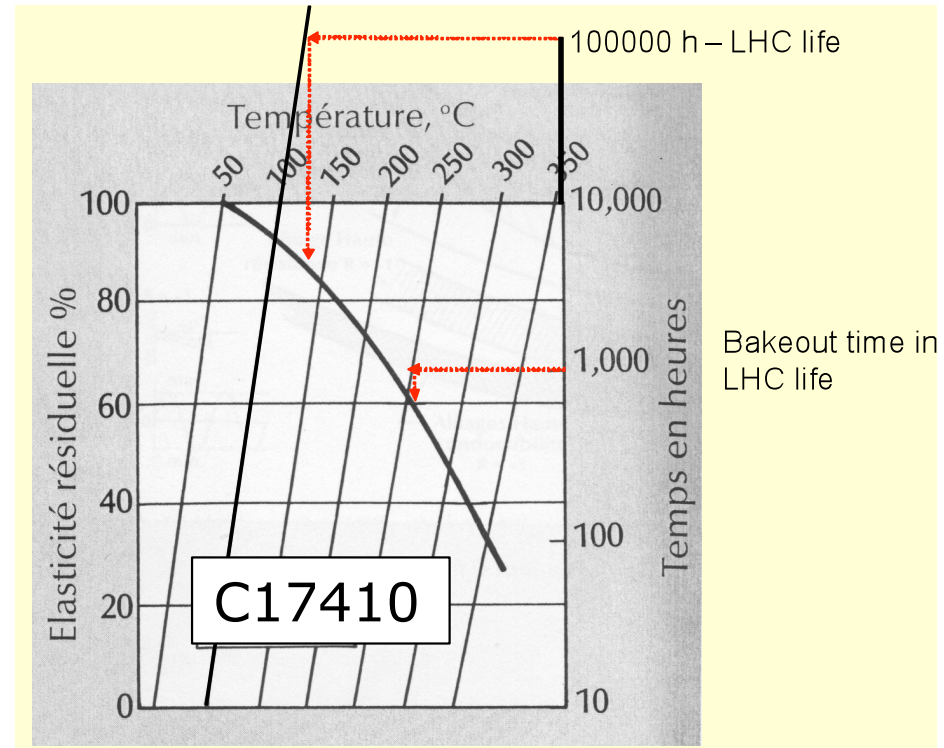
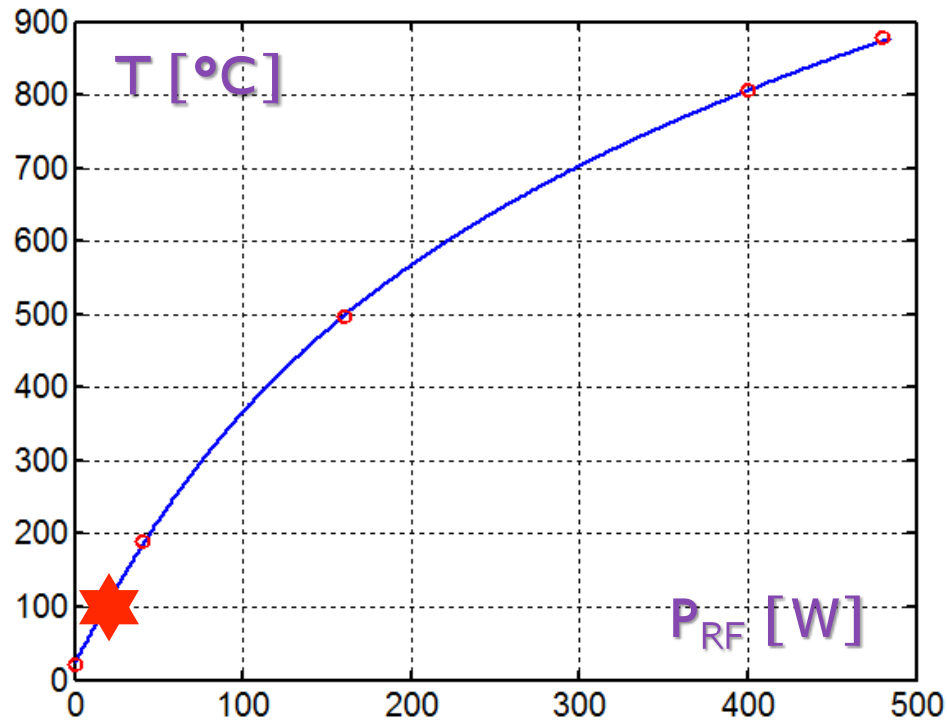


Temperatures expected for 650W (40mm gap)? **990°C**

Power expected for 1000°C? **670W** ★

# FOLLOW-UP OF VMTSA ISSUES IN 2011 (5/5)

Stress relaxation resistance (75% stress)



Temperature of the RF fingers

What could be a reasonable Power limit due to fingers failure?

$100^{\circ}\text{C} \rightarrow P_{RF} = 18\text{W} \star$



# CONCLUSIONS AND RECOMMENDATIONS (1/4)

- ◆ **A lot of experience has been accumulated at CERN over the past decades for the use of RF fingers and/or ferrite absorbers**
- ◆ **This experience needs to be (and will be) summarized in a forthcoming internal report**
  - Guidelines for the use of RF fingers
  - Guidelines for the use of ferrite absorbers
- ◆ **Several designs of RF fingers are used in the LHC depending on the requirements**
  - Some have been studied in great detail => Takes time but it paid off! Should really be done at the design stage: material, mechanics, beam-induced power, heat transfer etc.
  - Some less (due to time constraint, missing manpower etc.) but it can lead to big damages or intensity / bunch lengths limitations
  - New design from TE/VSC under checks => Should be carefully evaluated
  - Ferrite can be used in some cases as a back-up for RF fingers but it

## CONCLUSIONS AND RECOMMENDATIONS (2/4)

cannot be put like that => Requires detailed EM simulations (knowing the ferrite EM properties) to determine the frequency of the trapped mode(s), the location of maximum of magnetic field (where ideally the relevant ferrite should be put, ideally not seen by the beam) etc.

- **Ex: It was found by detailed EM simulations that the ferrite installed during a crash program ~ 1 year ago in the new VMTSA should not be effective as wrongly positioned...**

### ◆ **The VMTSA issues observed in 2011 have been reproduced by simulations and traced back to be due to a gap between some RF fingers and the central insert**

- Any gap is fatal for this equipment!
- The spring acted as a fuse => Robust mechanical design needed
- No issue at all this year => Our modifications during last year Xmas break's crash program were sufficient to assure a good contact

### ◆ **Full list of the 92 nonconformities revealed in warm modules after X-rays campaign => Should be repaired during LS1**

## CONCLUSIONS AND RECOMMENDATIONS (3/4)

- ◆ **For the cases studied, we didn't see any problem with impedance for conforming RF fingers => No (big) pb expected for HL-LHC bunch populations (i.e. up to  $2.2E11$  p/b for the 25 ns beam and  $3.5E11$  p/b for the 50 ns beam)**  
**=> Top priority for the future: Robust mechanical design to keep the contacts of all the RF fingers (e.g. with funnel as for the PIMs) + Very careful installation**
- ◆ **The beam-induced RF power loss of a trapped mode scales with the square of the total beam intensity**
  - Already done in the machine (1380 50 ns bunches,  $1.6E11$  p/b): 0.4 A
  - Nominal case (2808 25 ns bunches,  $1.15E11$  p/b): 0.58 A => Factor 2.1
  - HL-LHC case 1 (2808 25 ns bunches,  $2.2E11$  p/b): 1.11 A => Factor 7.7
  - HL-LHC case 2 (1404 50 ns bunches,  $3.5E11$  p/b): 0.89 A => Factor 4.9

**Assuming the same bunch length**

## CONCLUSIONS AND RECOMMENDATIONS (4/4)

- ◆ **BUT the big problem is the possible very short bunch of ~ 4 cm**
  - 2012 run made with ~ 10 cm rms bunch length
  - Nominal (rms) bunch length = 7.5 cm (for both LHC and HL-LHC) and ~ 4 cm was also considered for HL-LHC => Needs many careful checks!!

