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

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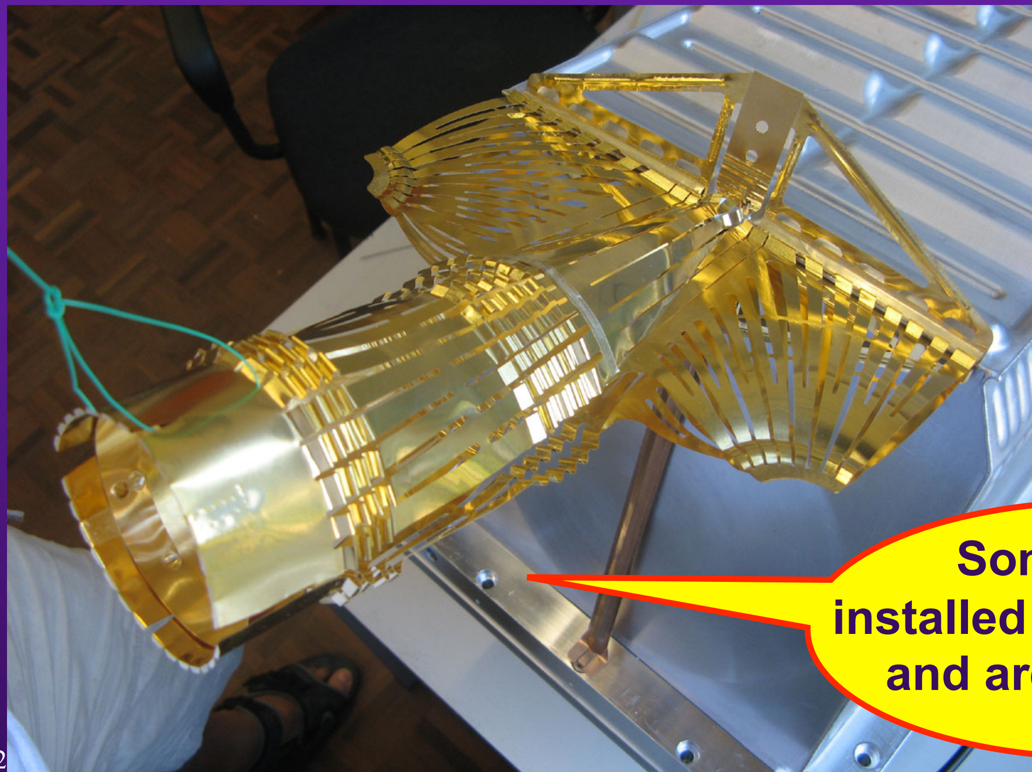


Some people installed this in the LHC and are very happy!

MELTED CHEESE TO AVOID MELTED EQUIPMENTS!

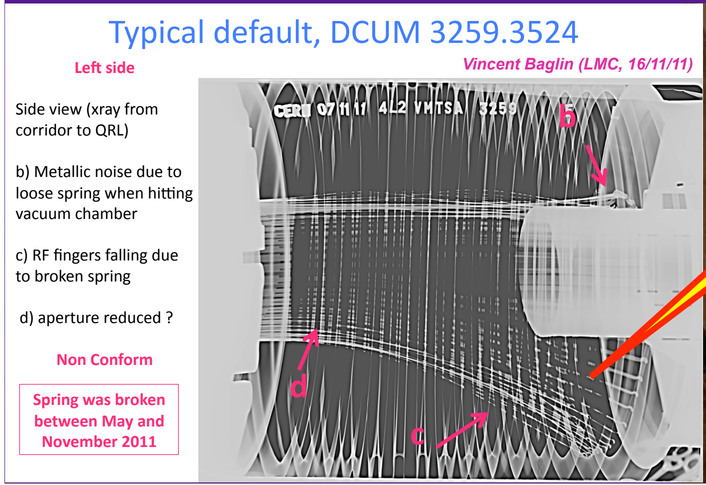
OUTLINE (for 15 min)

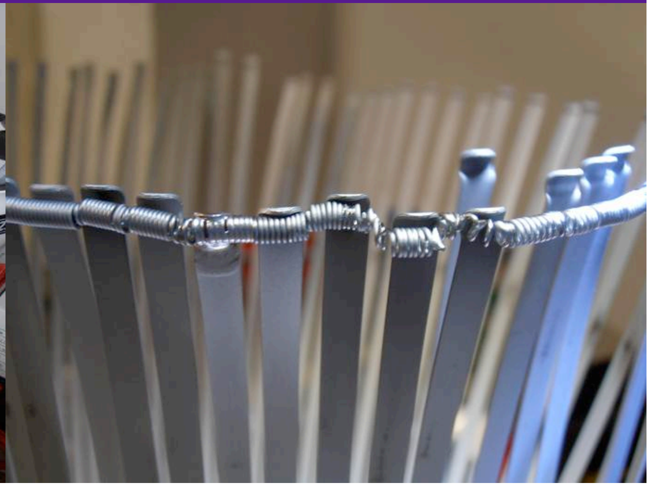
- Introduction
- Why do we need RF fingers and/or ferrite (absorbers)?
- Several designs for RF fingers
- Possible issues to consider with RF fingers
- Typical nonconformities in warm modules found with X-rays
- Conclusions and recommendations

- Appendix 1: List of all the (92) nonconformities
- Appendix 2: VMTSA found with defects in 2011 (8 bellows out of 20)
- Appendix 3: "Ideal" outline

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 ~ 800 - 1000 °C**





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
  - 1st (kick-off) meeting: 20/03/2012
  - 20th (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)

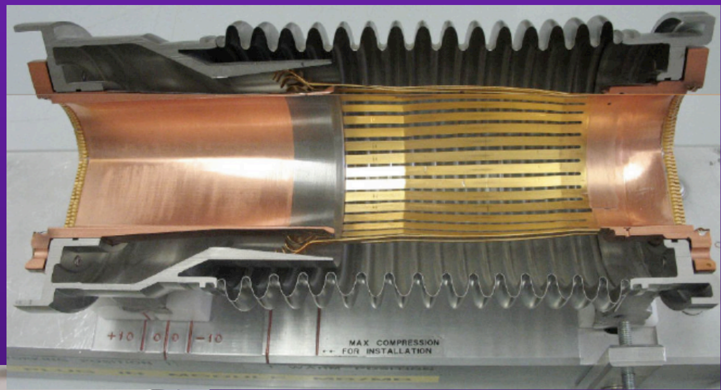
- **Mandate**
  - Review the design of all components of the LHC equipped with RF fingers, evaluate the compatibility with ultimate (and HL-LHC) bunch populations (i.e. up to 2.2E11 p/b for the 25 ns beam and 3.5E11 p/b for the 50 ns beam) and (rms) bunch lengths (i.e. 7.5 cm but also ~ 4 cm which could 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? (1/5)

- 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



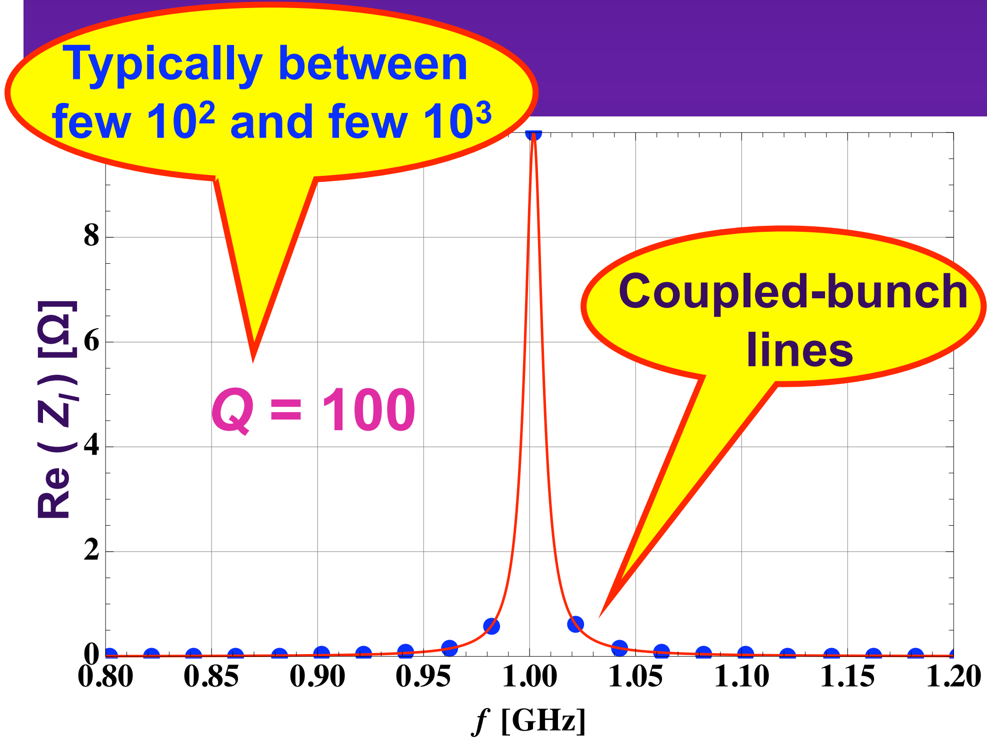
- Example of ferrite tiles:

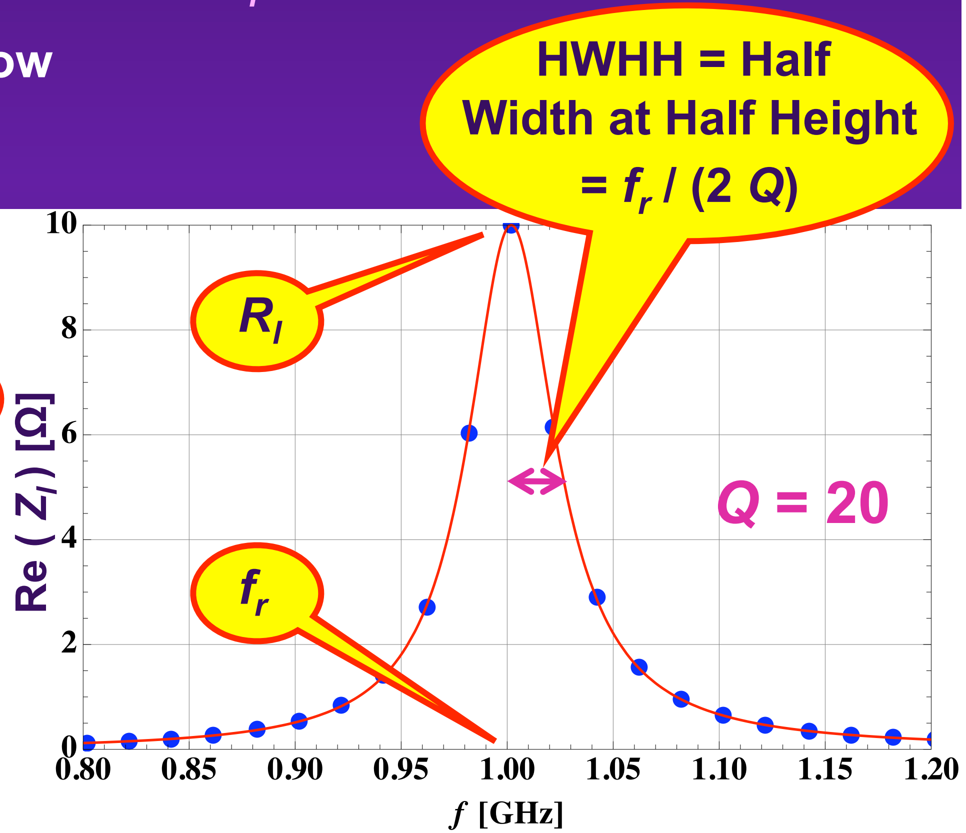
  Installed in the new VMTSA in 2012

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

WHY DO WE NEED RF FINGERS AND/OR FERRITE? (2/5)

- **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 Ω
  - Quality factor Q => Scanned below





WHY DO WE NEED RF FINGERS AND/OR FERRITE? (3/5)

- **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 = # bunches
$I_b = N_b\, e\, f_0$

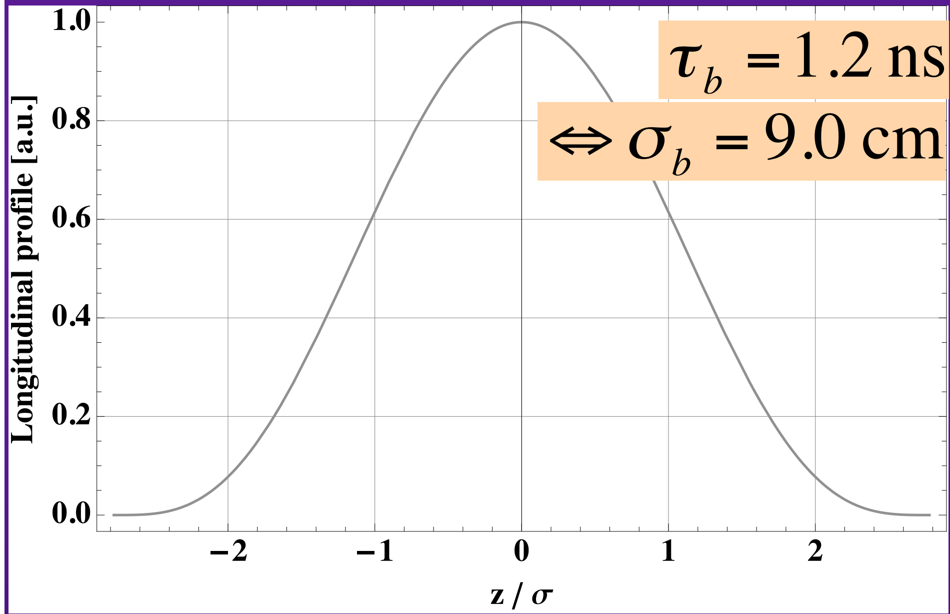
~ 1 for HL-LHC

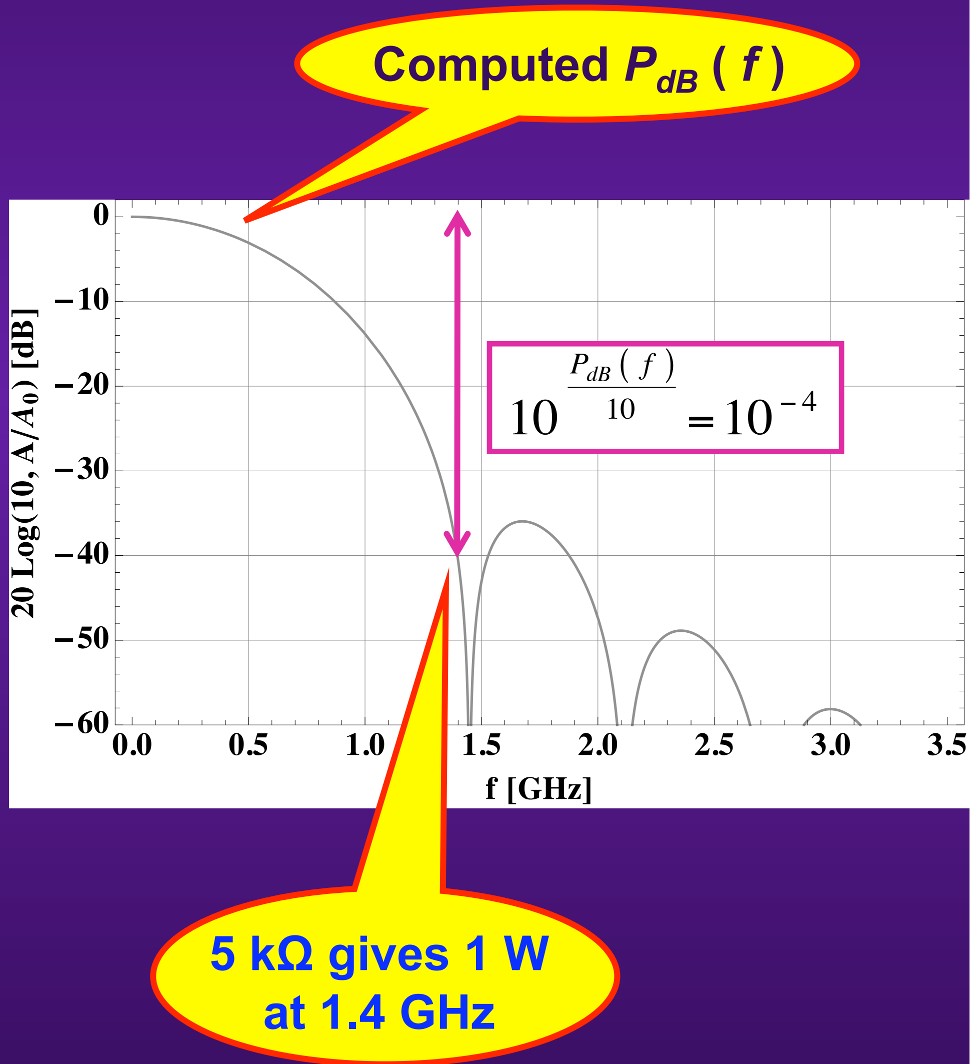
$P_{dB}(f_r)$ is the power in dB read from a power spectrum (computed or measured) at the frequency f_r

Typically below few 10s of kΩ (between few 100s Ω and few kΩ)

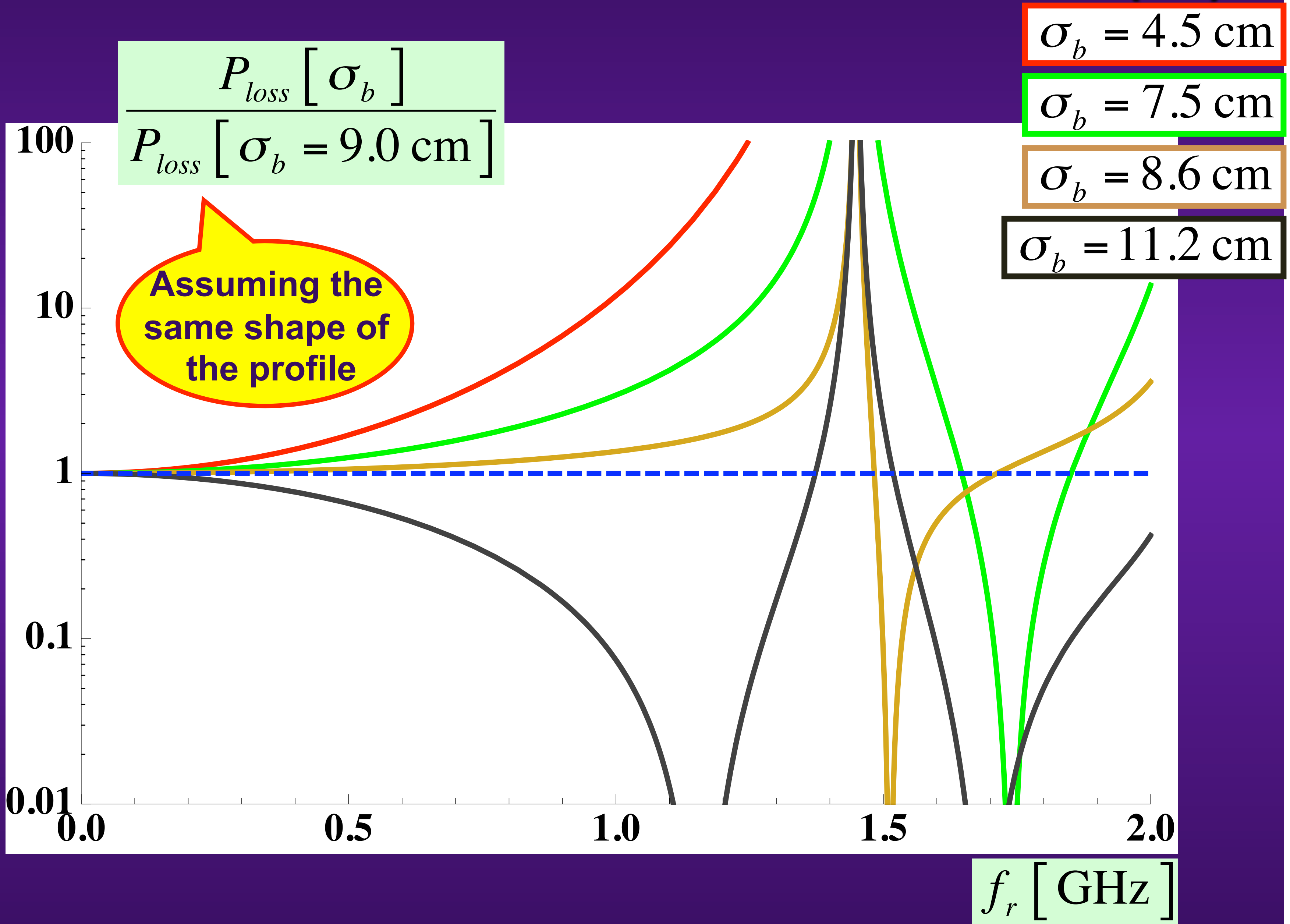
WHY DO WE NEED RF FINGERS AND/OR FERRITE? (4/5)

- Consider the following (analytical) distribution



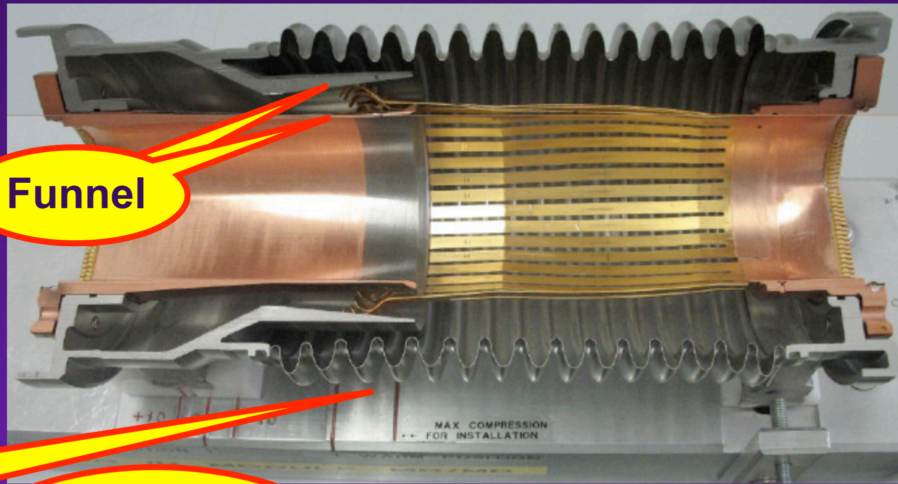


WHY DO WE NEED RF FINGERS AND/OR FERRITE? (5/5)

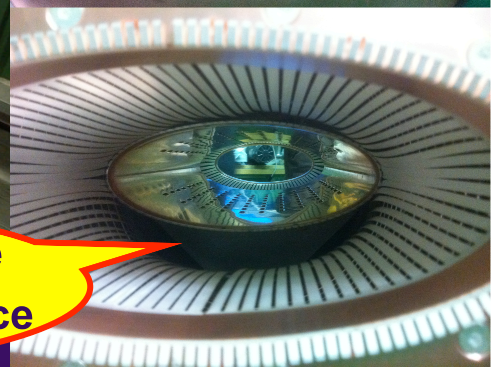


SEVERAL DESIGNS FOR RF FINGERS (1/3)

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

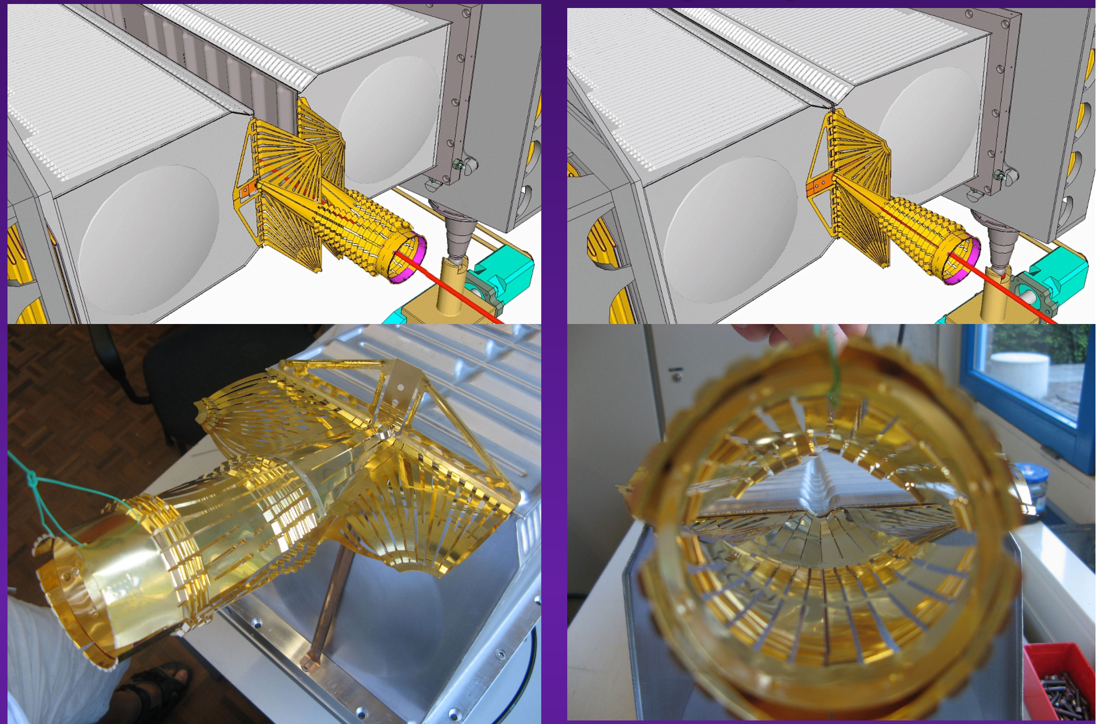


- **2) Spring for the VMTSA**
  - For case of transversal movement
  - Possible issue with contact / gap (due to elliptical shape) => RF heating
  - Possible issue with aperture restriction

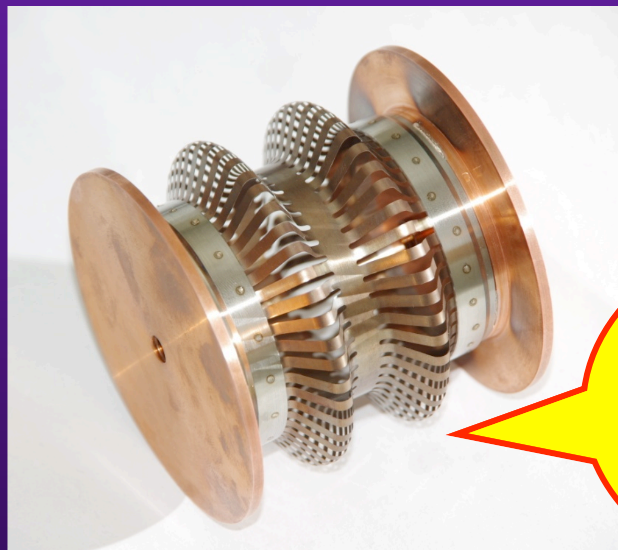


SEVERAL DESIGNS FOR RF FINGERS (2/3)

- **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)



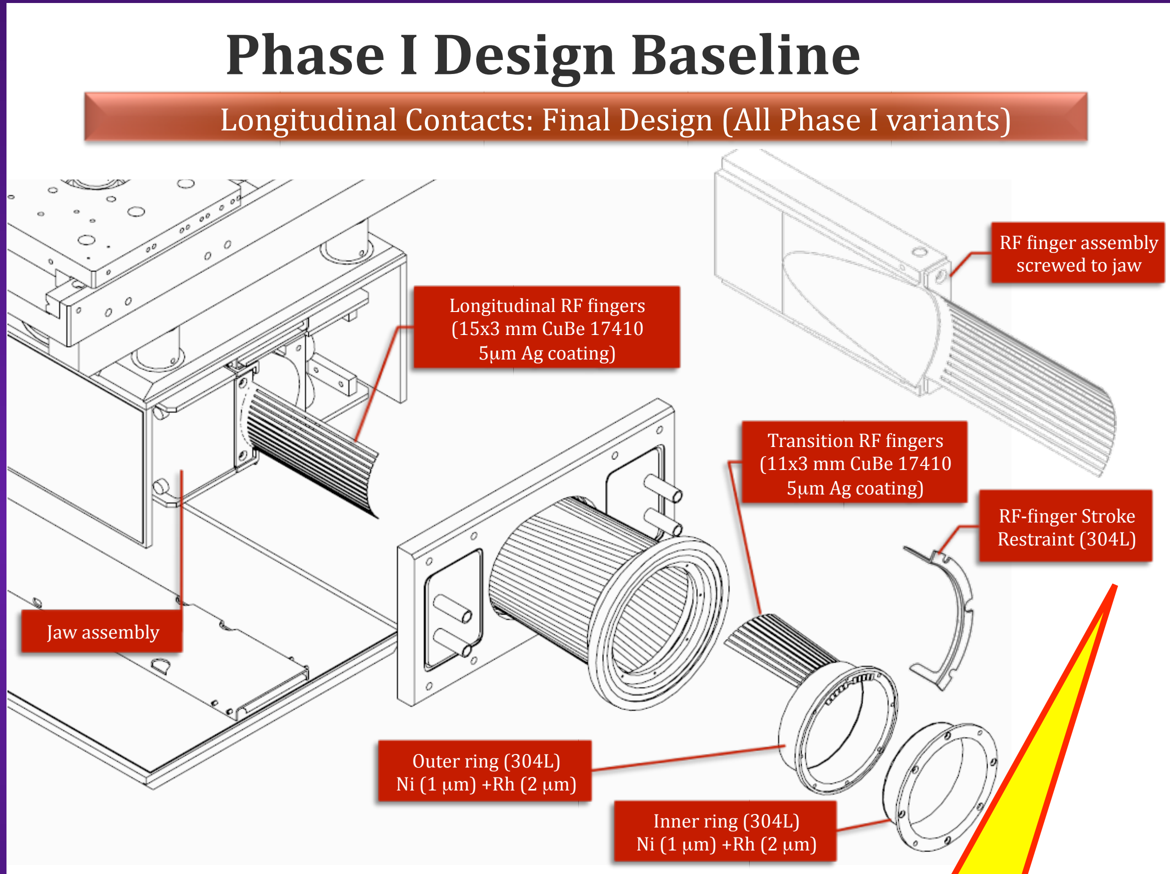
- **4) New RF design from TE/VSC**
  - 1st prototype based on 2 convolutions manufactured this year. Tests ongoing
  - Issue: Imaginary part of the longitudinal impedance (if many and not elongated)

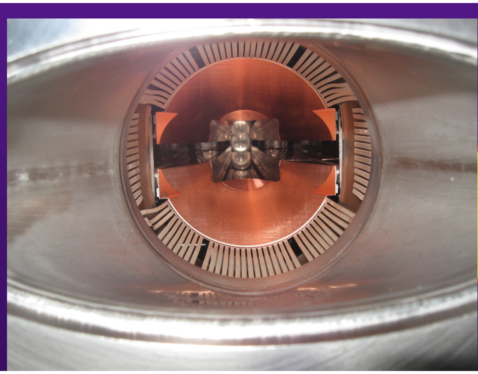


Device EM longer than mechanically due to induced current having to follow the convolutions

SEVERAL DESIGNS FOR RF FINGERS (3/3)

- **5) Longitudinal sliding contacts for collimators**
  - Initial proposal for 1st (SPS) prototype (2003)
  - Uncoated CuBe fingers sliding on C/C
  - Electrical contact resistance ~ 30 mΩ (specification: 1 mΩ) => Redesign necessary





Solution to the pb observed with the TCDD

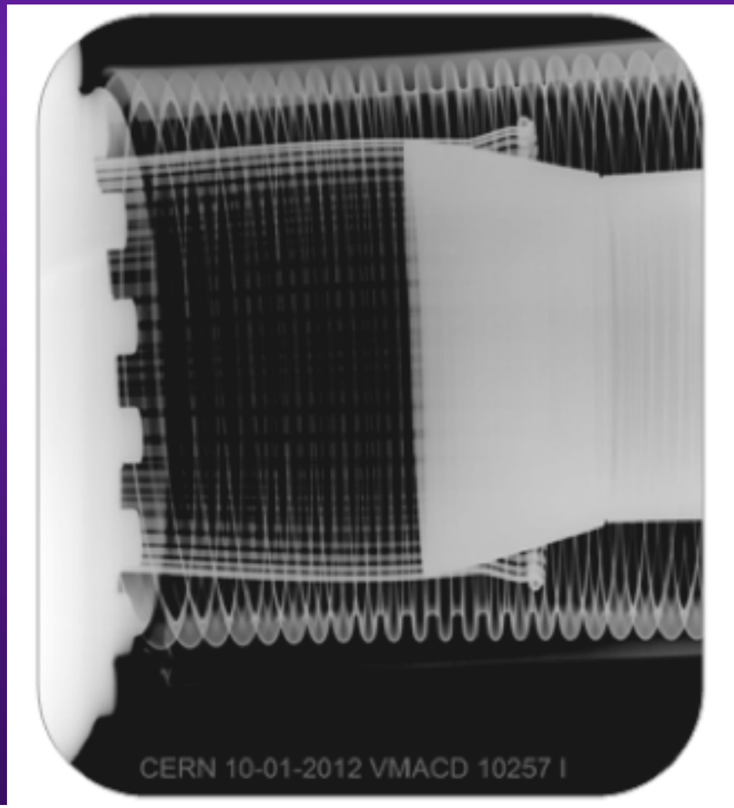
POSSIBLE ISSUES TO CONSIDER WITH RF FINGERS

- **RF fingers for PIMs**
  - **Low contact resistance < 0.1 mΩ (i.e. 3 mΩ / 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 mΩ**
  - **Resistance to bake out: 250°C / 1000 h**
  - **Resistance to heating => Good thermal conductivity**
  - **Wear after many cycles "open-close of the jaws" (1500 cycles ~ 4 years)**
- **Good electric contacts requires**
  - **Low surface roughness**
  - **Soft metals (at least one)**
  - **No oxide layer at the surface**

TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (1/2)

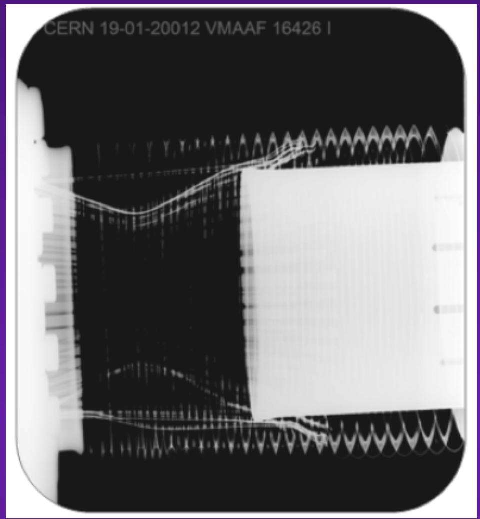
- **1800 X-rays taken**
- **92 NC (~ 5 %) => 2 types of design: circular and elliptical (VMTSA)**
- **58 vacuum sectors concerned out of 190 at room temperature (88 sectors at cryogenic temperature)**

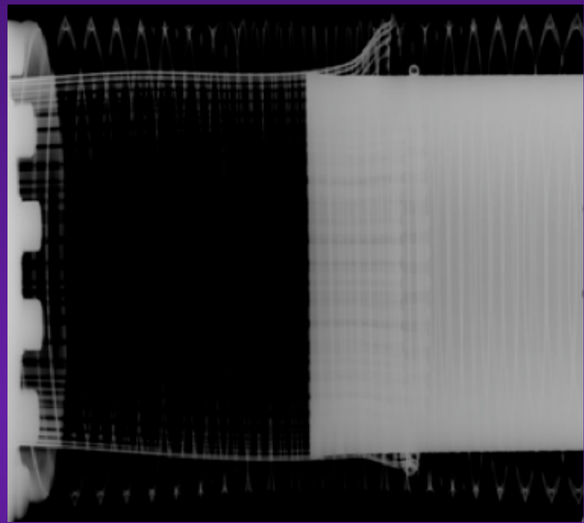
CONFORMITY

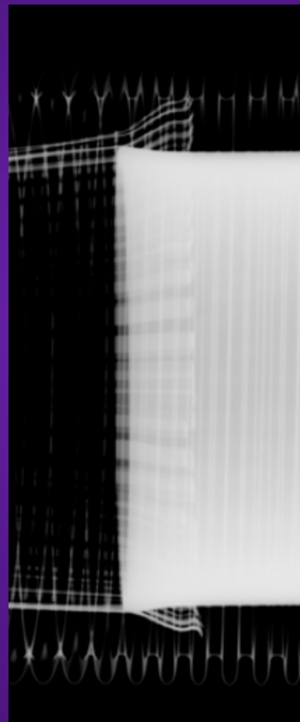


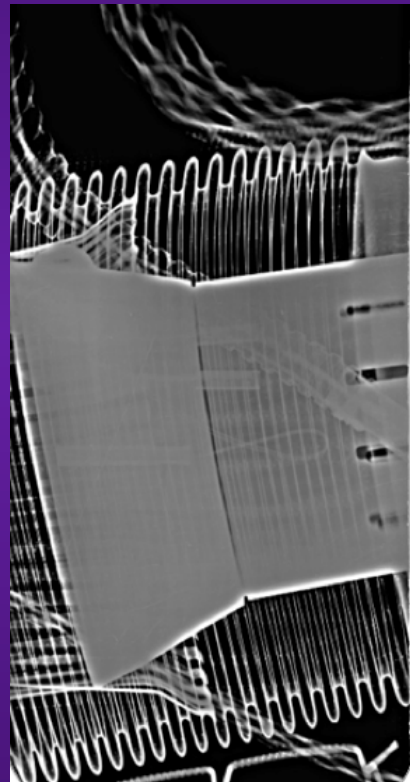
TYPICAL NONCONFORMITIES IN WARM MODULES FOUND WITH X-RAYS (2/2)

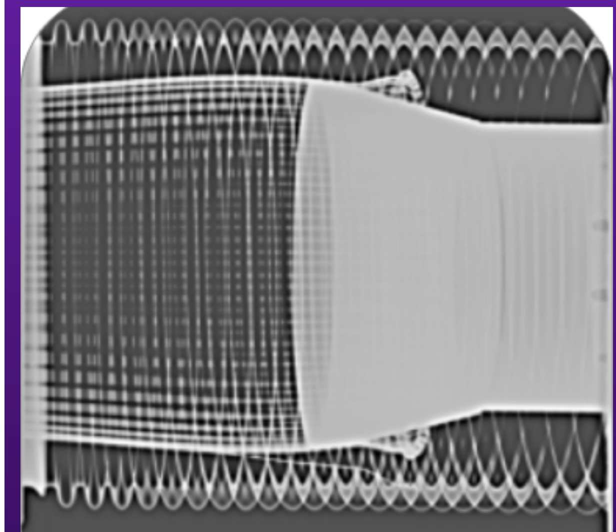
NONCONFORMITIES

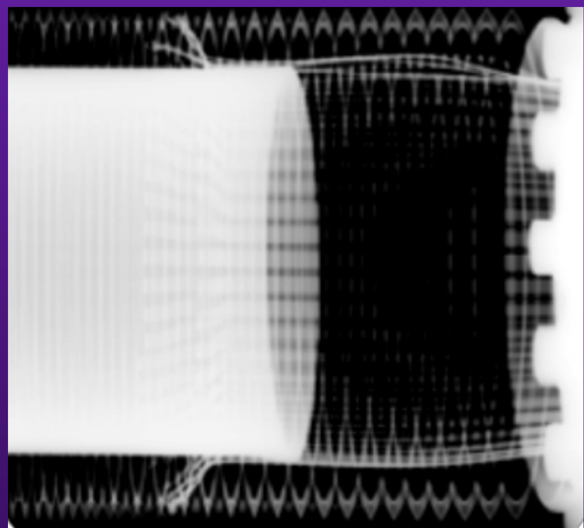








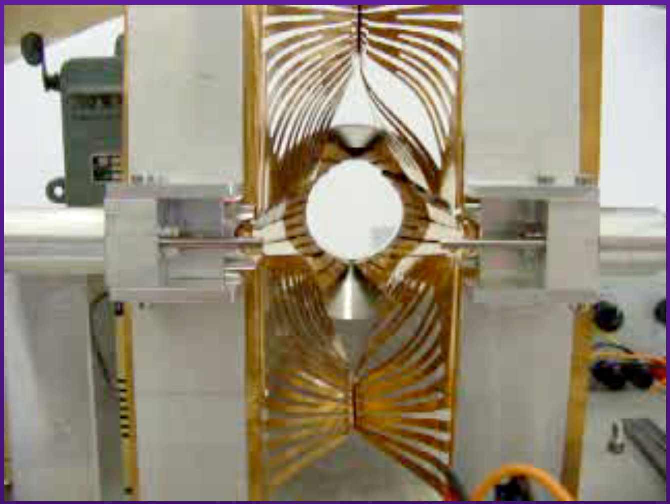




CONCLUSIONS AND RECOMMENDATIONS (1/3)

- 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 => Nominated "ferrite responsible persons" at CERN: Fritz Caspers and Christine Vollinger
- 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!



  - New design from TE/VSC under careful checks

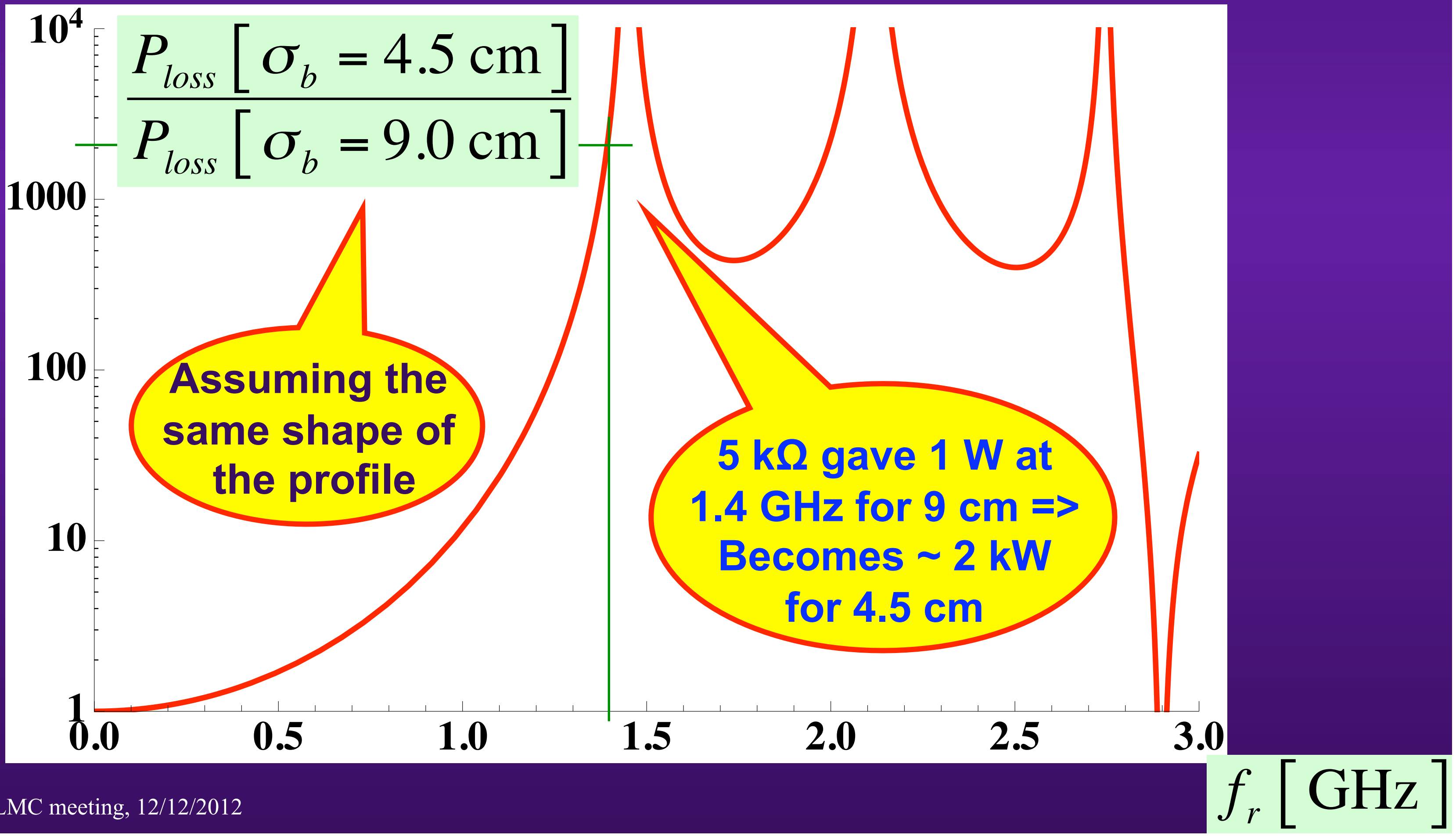
CONCLUSIONS AND RECOMMENDATIONS (2/3)

- VMTSA issues observed in 2011 have been reproduced by simulations and traced back to be due to a gap between some RF fingers and central insert
  - 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
  - All the VMTSA modules will be removed during LS1
- Full list of the 92 nonconformities revealed in warm modules after X-rays campaign => Should be repaired during LS1
- 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, or fixed extremities) + Very careful installation

CONCLUSIONS AND RECOMMENDATIONS (3/3)

- **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!!



APPENDIX 1: 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 deformes 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

APPENDIX 1: LIST OF ALL NONCONFORMITIES (2/3)

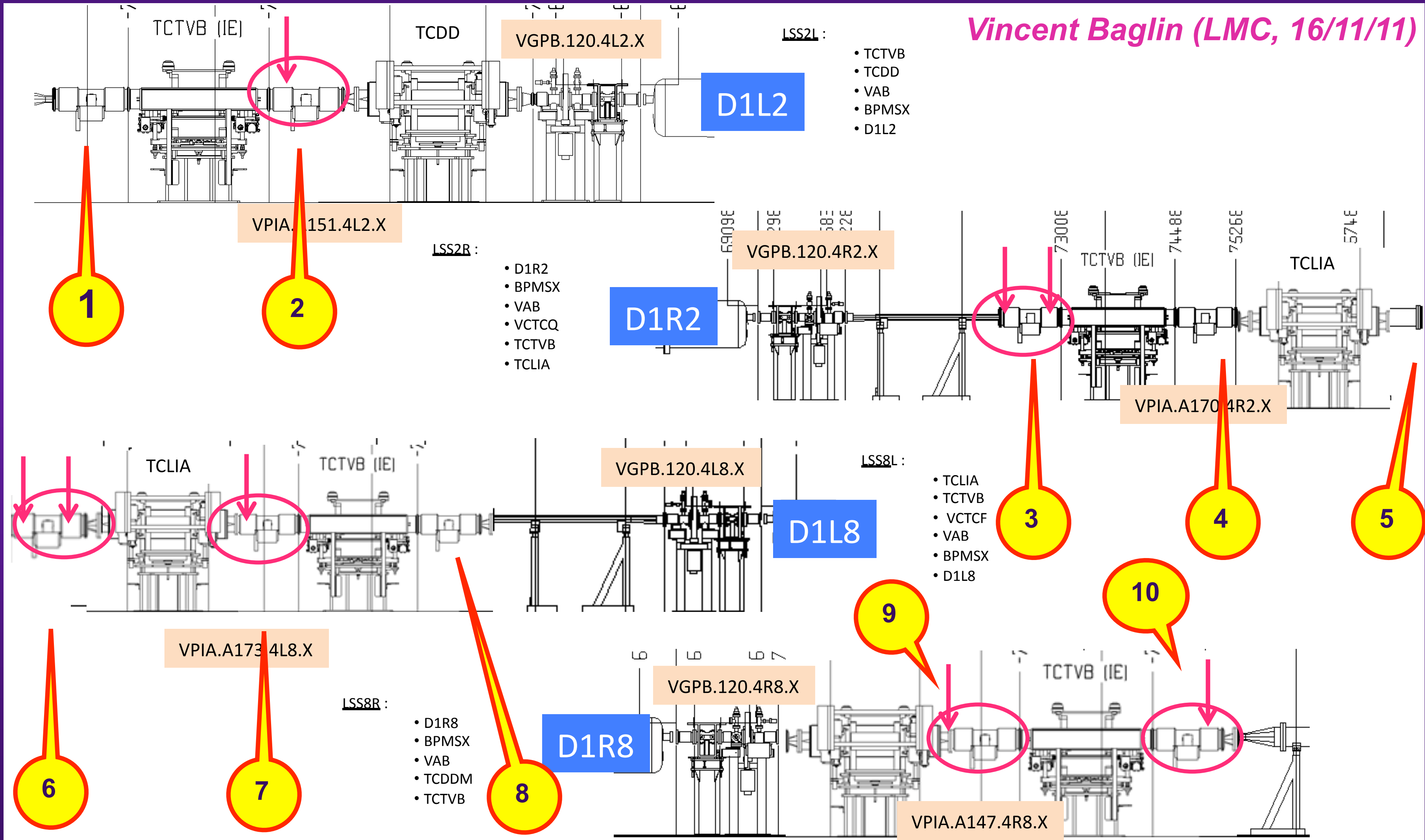
31	LSS4	D5R4.B	VMAAB	10056.0122	distance recouvrement nulle	2
32	LSS4	D5R4.B	VMBGA	10063.3122	ressort hors logement, leger flambage interne des doigts	1
33	LSS4	D5R4.R	VMAAF	10063.1472	ressort hors logement	2
34	LSS4	E5R4.B	VMAAE	10084.9402	ressort hors logement, leger flambage interne des doigts	1
35	LSS4	E5R4.R	VMAAF	10084.9402	ressort de traction hors logement, doigts deformes	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 deformes et coinces 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 coinces dans ondulations	2
49	LSS5	A4R5.C	VMBGA	13443.6416	absence ressort, qq doigts Rf coinces 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

APPENDIX 1: 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 coinces entrainant 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

APPENDIX 2: VMTSA FOUND WITH DEFECTS IN 2011

=> 10 modules (each of 2 bellows) in total in 2011. 8 bellows were found with defects (see arrows below)



APPENDIX 3: "IDEAL" OUTLINE (1/2)

But no time in 15 min

- 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

APPENDIX 3: “IDEAL” OUTLINE (2/2)

But no time in 15 min

- 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

=> See last meeting of the LRFF TF: http://emetral.web.cern.ch/emetral/LRFF/20thMeeting_27-11-12/LRFF_EM_03-12-12_AfterMeetingComments_Final.pptx (76 slides)

=> See yesterday’s summary at TE-TM: http://emetral.web.cern.ch/emetral/LRFF/SummaryAtTE-TM_11-12-12/LRFF_EM_11-12-12_TE-TM.pptx (55 slides)