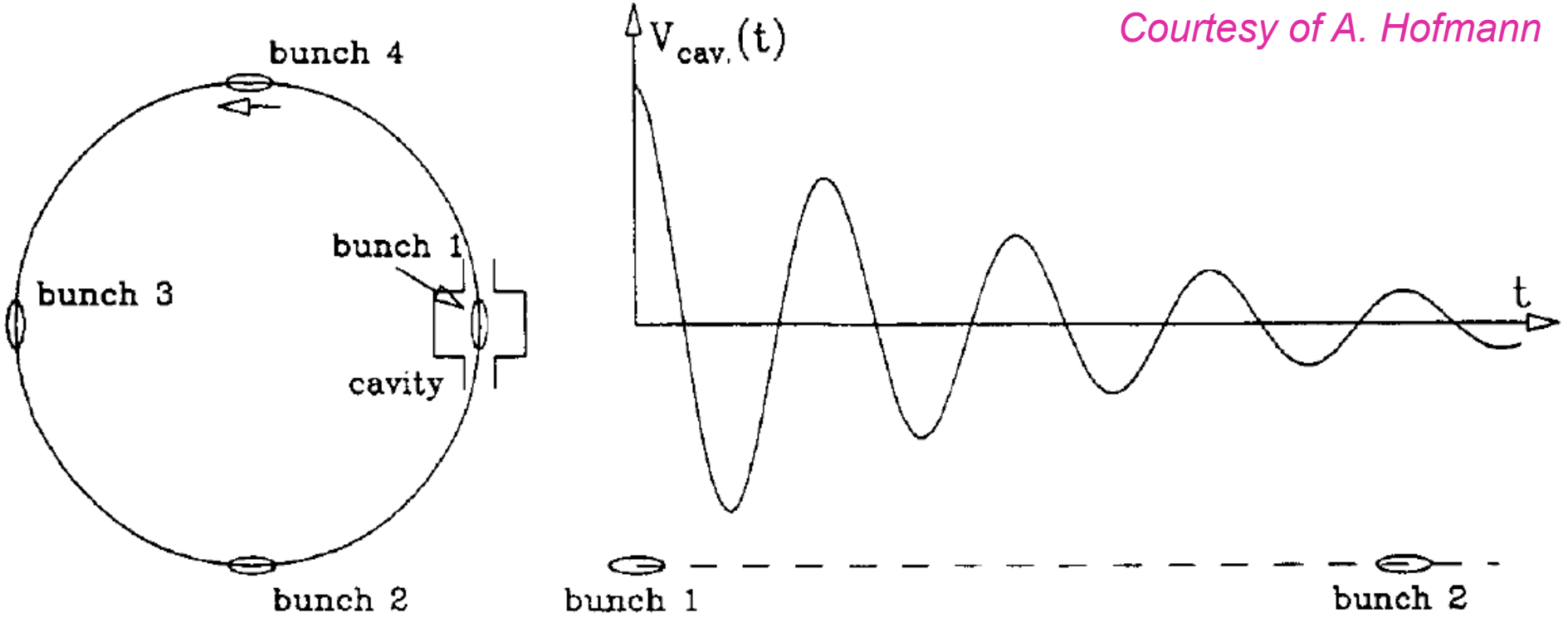
RF CONSIDERATIONS FOR THE LHC TOTEM RPs

Elias Métral

- **Reminder on impedances**
- **LHC impedances and guidelines**
- **Impedances of the TOTEM RPs**
- **Conclusion**

REMINDER ON IMPEDANCES (1/7)

- **Wake fields** = Electromagnetic fields generated by the beam interacting with its surroundings (vacuum pipe, etc.)
  - Energy loss
  - Beam instabilities
  - Excessive heating



Courtesy of A. Hofmann

REMINDER ON IMPEDANCES (2/7)

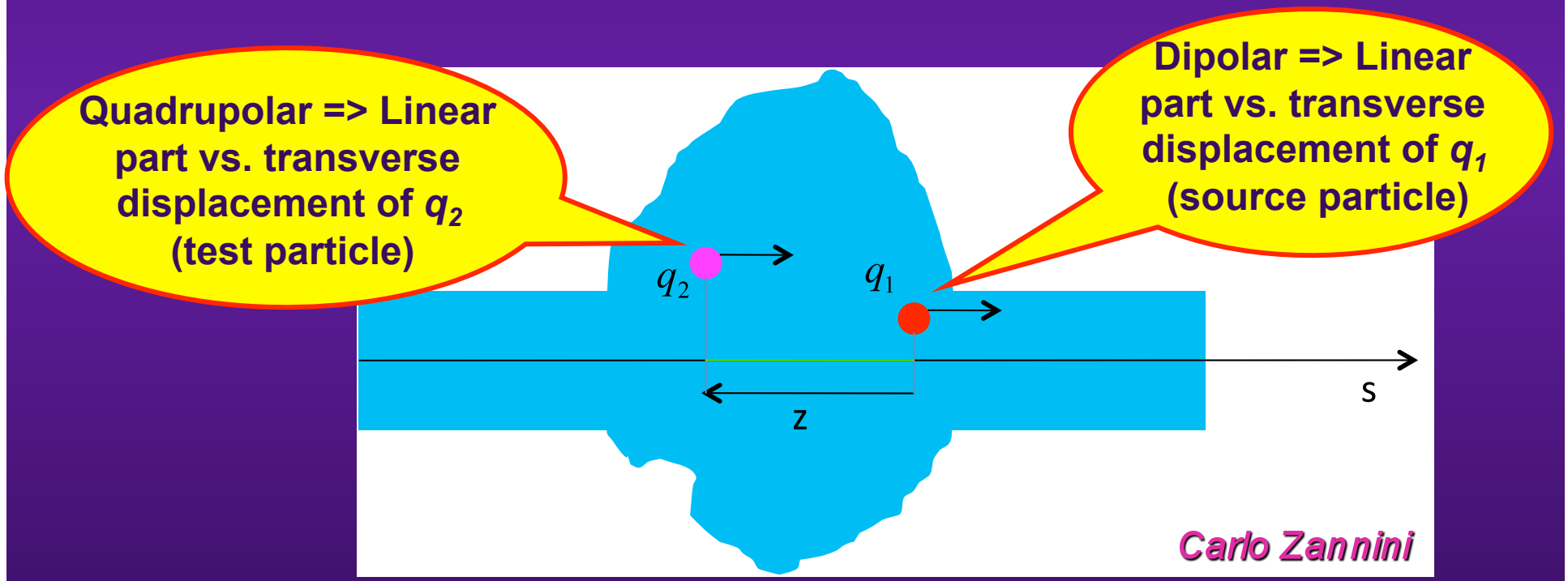
- Impedance = Fourier transform of the wake field
- Origin of the impedance in the previous case is coming from a (abrupt) change of geometry (cavity, trapping some EM fields) => Usually computed using EM simulation codes
- Can come also from a smooth pipe due its finite conductivity (considering also permittivity and permeability) => Available theories

  => Usually the geometric and resistive parts are treated separately but both contributions should be added

- An impedance is a complex function of frequency => Interesting frequency range for the LHC: few kHz to few GHz

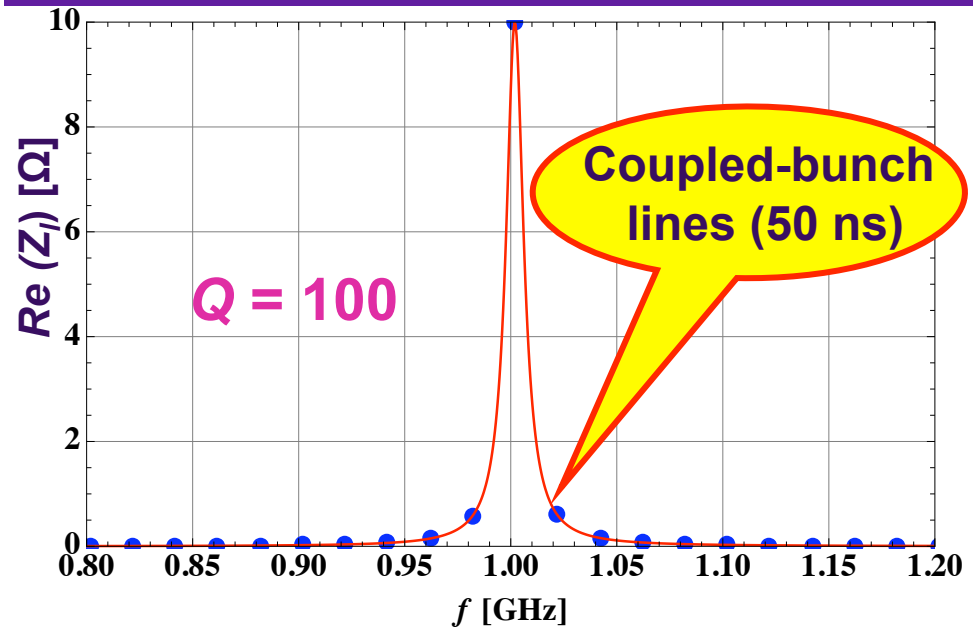
REMINDER ON IMPEDANCES (3/7)

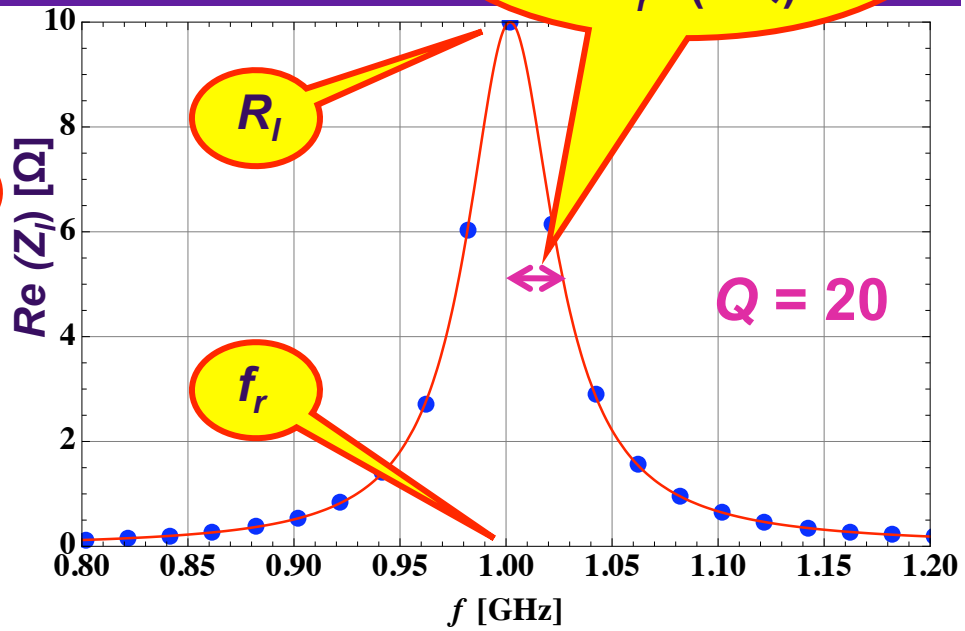
- (At least) 5 impedances are needed to describe the beam dynamics
  - Longitudinal
  - Horizontal => Dipolar and quadrupolar
  - Vertical => Dipolar and quadrupolar



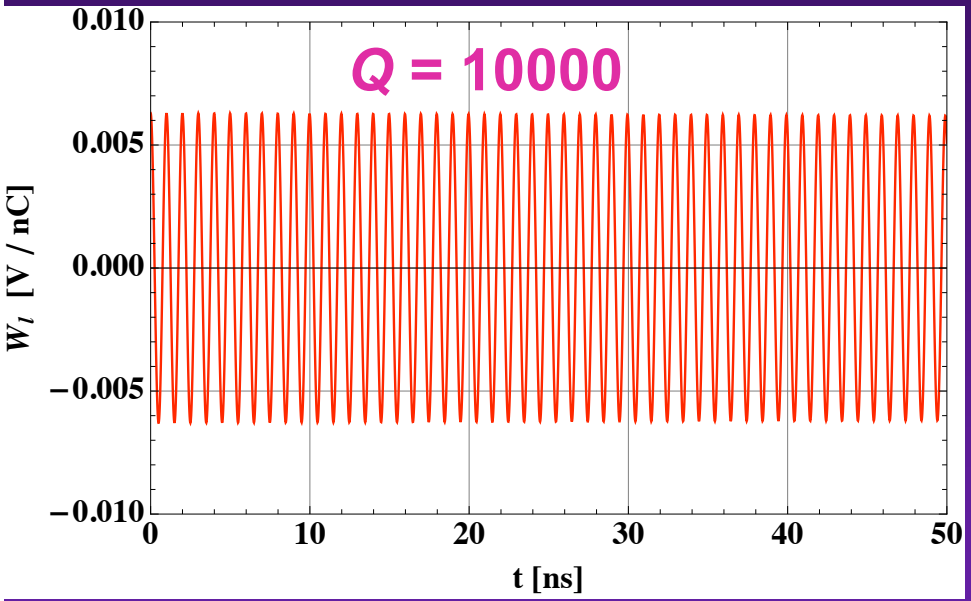
REMINDER ON IMPEDANCES (4/7)

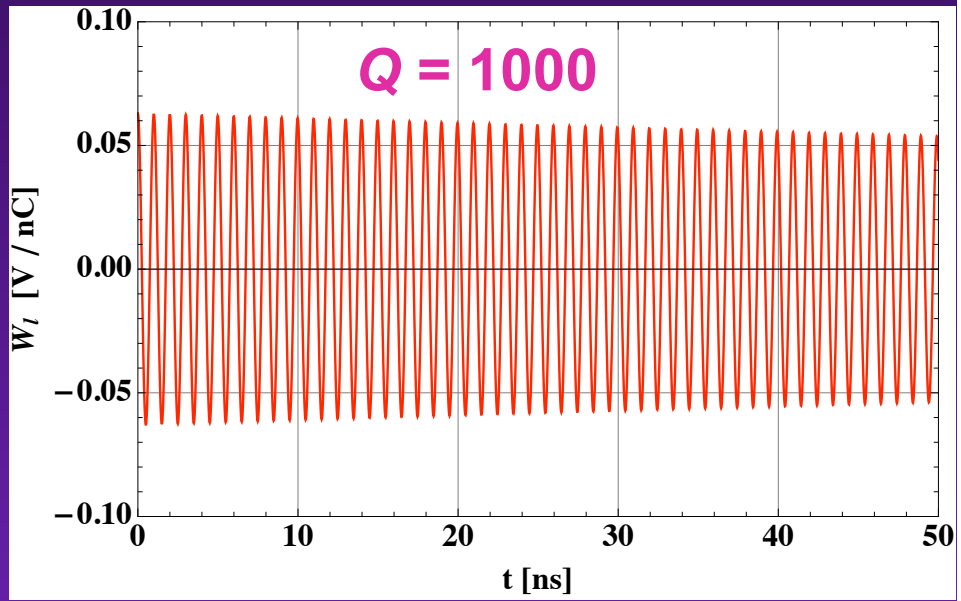
- Consider now the case of a longitudinal narrow resonance (trapped mode due to geometry) => 3 parameters:
  - Resonance frequency => Assumed to be here f_r = 1 GHz
  - Shunt impedance => Assumed to be here R_l = 10 Ω
  - Quality factor Q => Scanned below

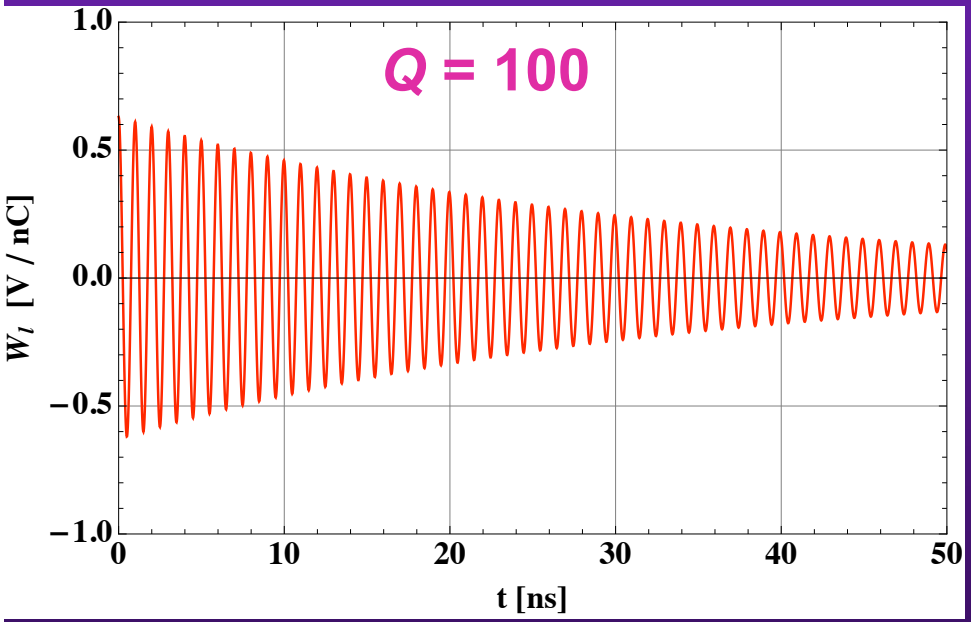


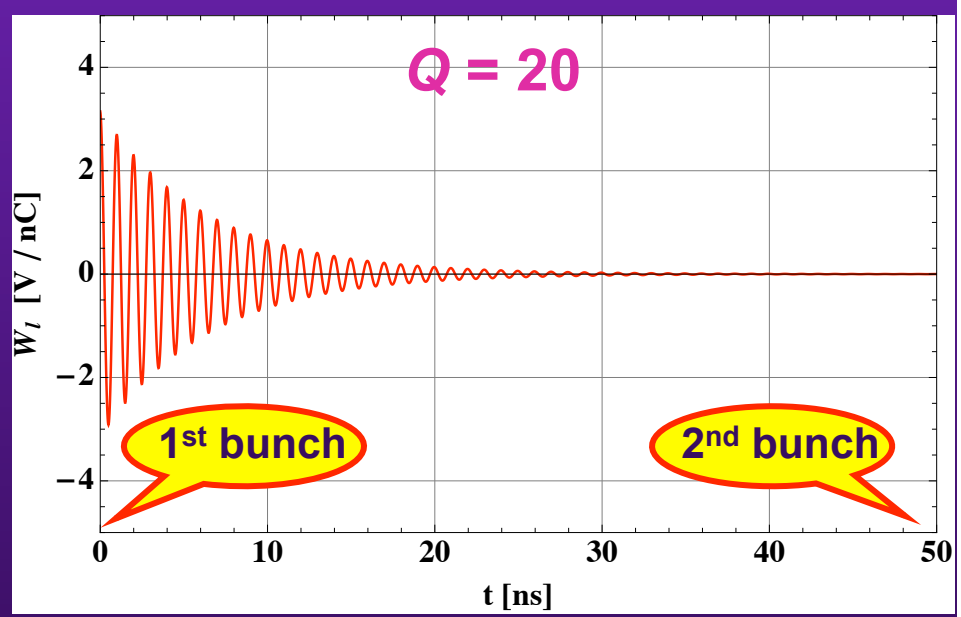


REMINDER ON IMPEDANCES (5/7)









REMINDER ON IMPEDANCES (6/7)

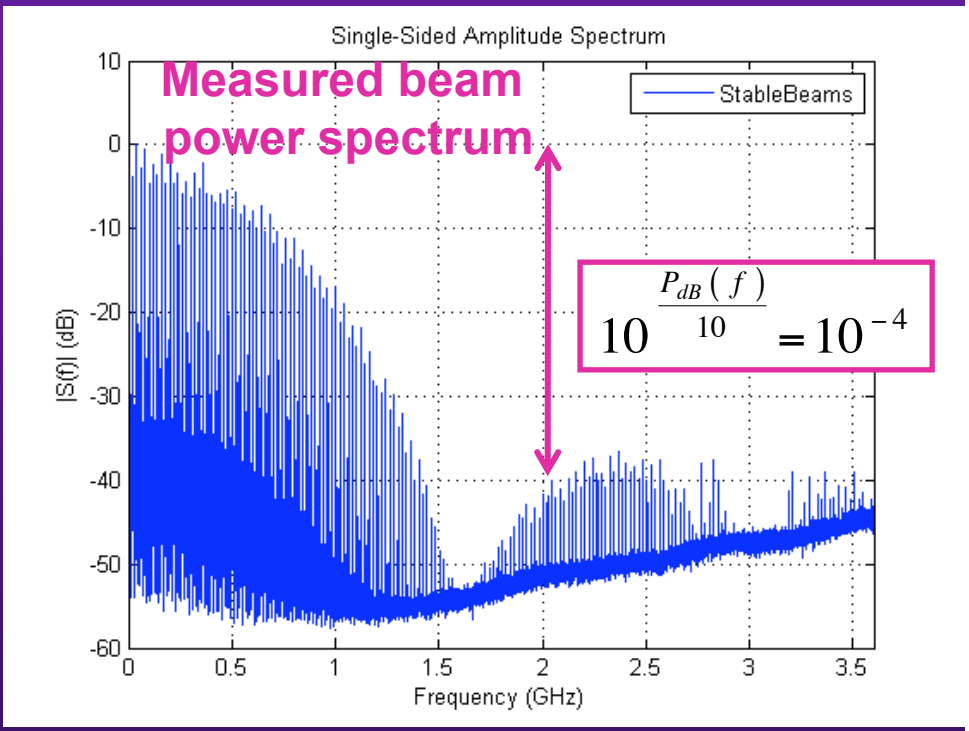
- **Power loss formula for the case of a (sharp) resonance (i.e. with only 1 line), i.e. for**

$$Q >> \frac{f_r}{2\, f_b}$$

Bunch frequency

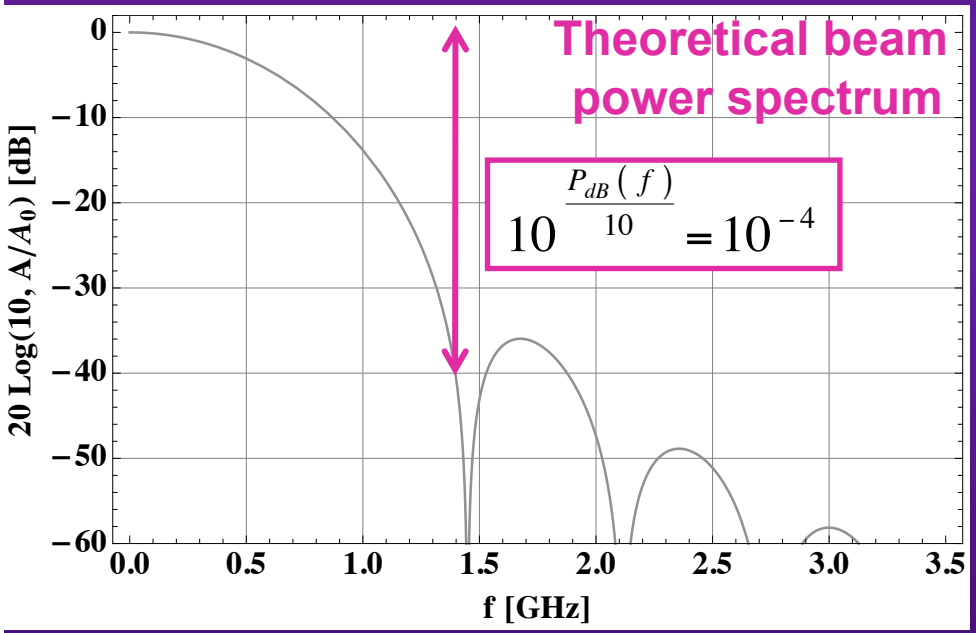
Total beam current (1 beam)

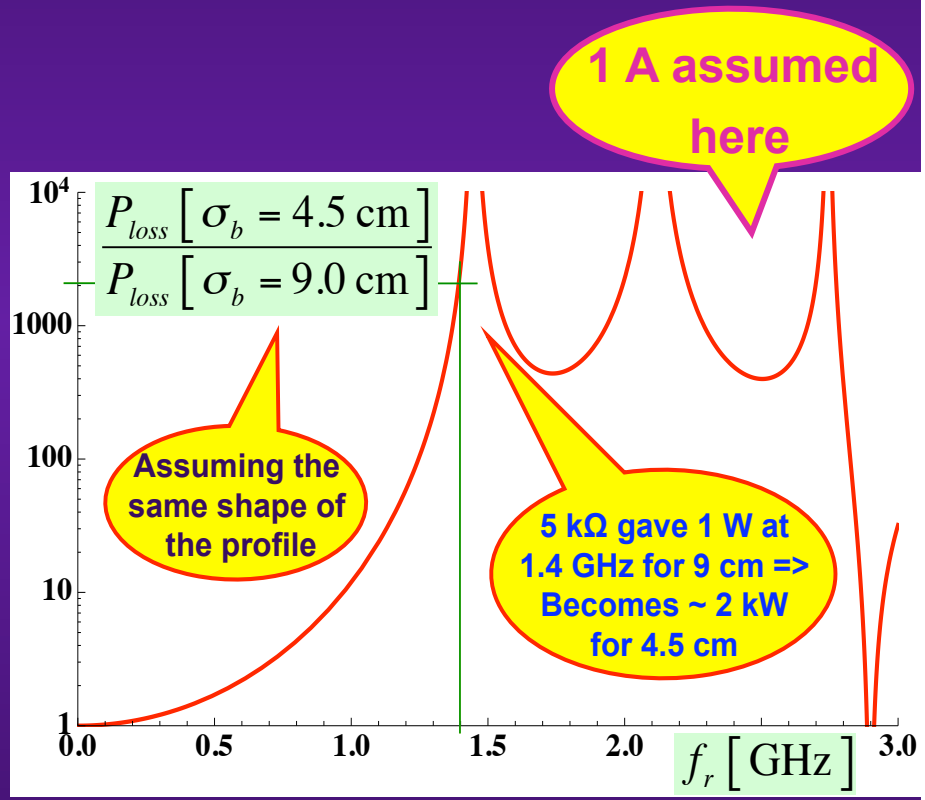
$$P_{loss} = I_{total}^2 \times 2\, R_l \times 10^{\frac{P_{dB}(f_r)}{10}}$$



REMINDER ON IMPEDANCES (7/7)

- **Consider the hypothetical case of a sharp resonance of 5 kΩ at 1.4 GHz => Effect of a bunch length change from 9 cm to 4.5 cm**

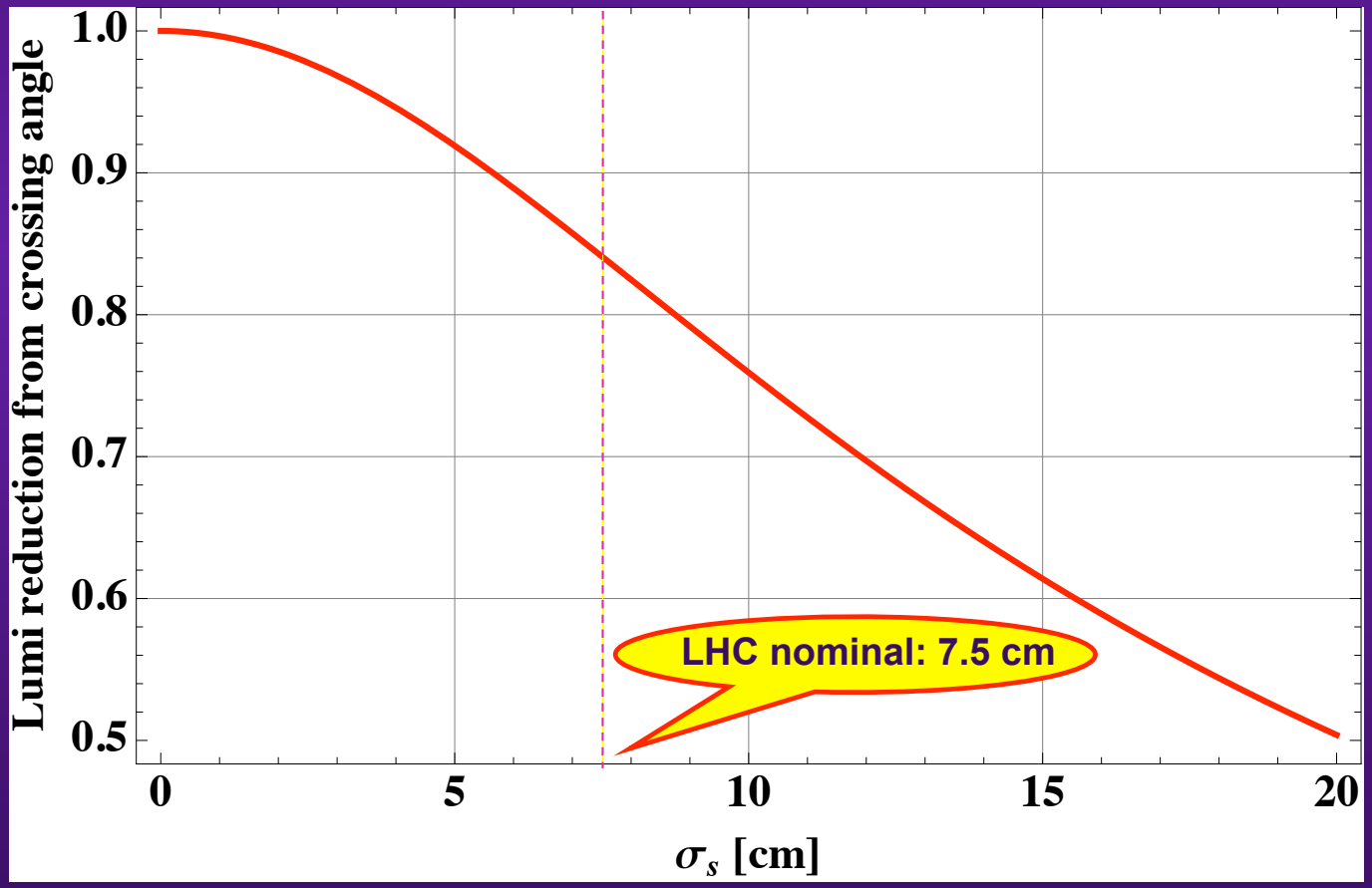




LHC IMPEDANCES AND GUIDELINES (1/7)

- **2 major concerns in 2011-2012**
  - **Beam-induced RF heating!**

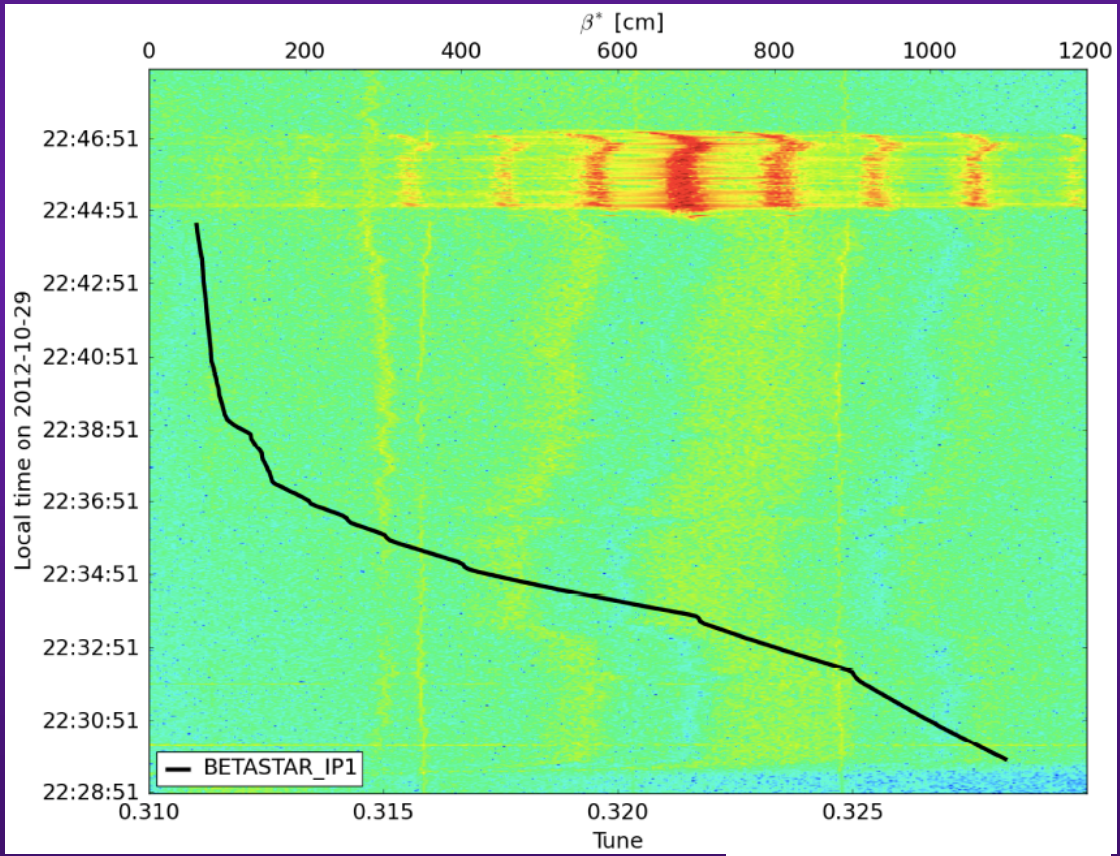
=> This is why the rms bunch length was ~ 9 cm in 2011 and ~ 10 cm in 2012



LHC IMPEDANCES AND GUIDELINES (2/7)

- **Many instabilities and 1 instability remained at the end of 2012 (at the end of the β^* squeeze) without a clear understanding => It is therefore a worry for the future…**

Fill 3238 (Monday 29/10 evening)



Nicolas Mounet

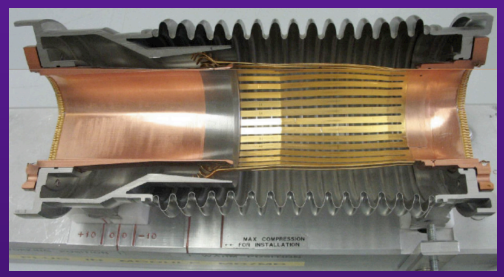
LHC IMPEDANCES AND GUIDELINES (3/7)

- **However, overall the machine worked very well**
  - **Peak luminosity record: 77% of design luminosity with**
    - **57% of design energy**
    - **½ number of bunches**
  - **Bunch brightness : ~ (1.6 / 1.15) × (3.75 / 2.2) ~ 2.4 times larger than nominal**
    - **~ 1.6 10^{11} p/b => 39% more particles than nominal**
    - **~ 2.2 μm => 70% smaller transverse emittance (and there was blow-up in the LHC…)**

=> Thanks to the people who designed the LHC and the past impedance police!

LHC IMPEDANCES AND GUIDELINES (4/7)

- **Past recommendations => General guidelines**
  - Tapering angle => Famous 15 deg (this is a general recommendation / trade-off but ideally should be re-evaluated carefully for each design)
  - Copper coatings
    - Beam-induced RF heating => Usually only few μm enough (high-frequency mechanism)
    - Transverse coupled-bunch instability => Could be larger (can also be a low-frequency mechanism)
  - Ferrite to damp some trapped modes (reducing the Q factor while keeping R_l / Q almost constant)
  - Shielding of bellows, Etc.



- **Recommendations for the future**
  - Similar + we try and do all the simulations + we should try and decrease the impedances of new / replaced equipments…

LHC IMPEDANCES AND GUIDELINES (5/7)

- **Guidelines mentioned by Benoit Salvant in some of his talks**

General view on what can be accepted from the impedance team point of view for a change to the LHC impedance (for the low frequency part which impacts beam stability)

These are orders of magnitude, and are drafts still subject to discussions

Ratio device change/total LHC impedance	Impedance team opinion	Management decision required
Less than 0	Very happy!	no
Less than 0.1%	Should be OK if valid arguments	no
Between 0.1% and 1%	Can be discussed if strong arguments	no
Between 1% and 10%	Does not agree	yes
Above 10%	**Strongly objects**	yes

LHC IMPEDANCES AND GUIDELINES (6/7)

- Need for efficient cooling of near-beam equipment to avoid what happened to TDI, BSRT and ALFA
- Maximize evacuation of heat (optimize emissivity, thermal conduction)
- Need to ensure good RF contact to avoid what happened to VMTSA
- Use high Curie temperature ferrites whenever possible (e.g. Transtech TT2-111R => To be treated at high temperature to be compatible with UHV)
- Need for more monitoring of temperature inside critical equipment (e.g.: TDI, BSRT, etc.)

LHC IMPEDANCES AND GUIDELINES (7/7)

- **Comparison between predictions and measurements**
  - **Longitudinal imaginary effective impedance:**

PREDICTION	MEASUREMENT
• **Injection and 7 TeV: ~ 90 mΩ**	• **From loss of LD: ~ 90 mΩ**

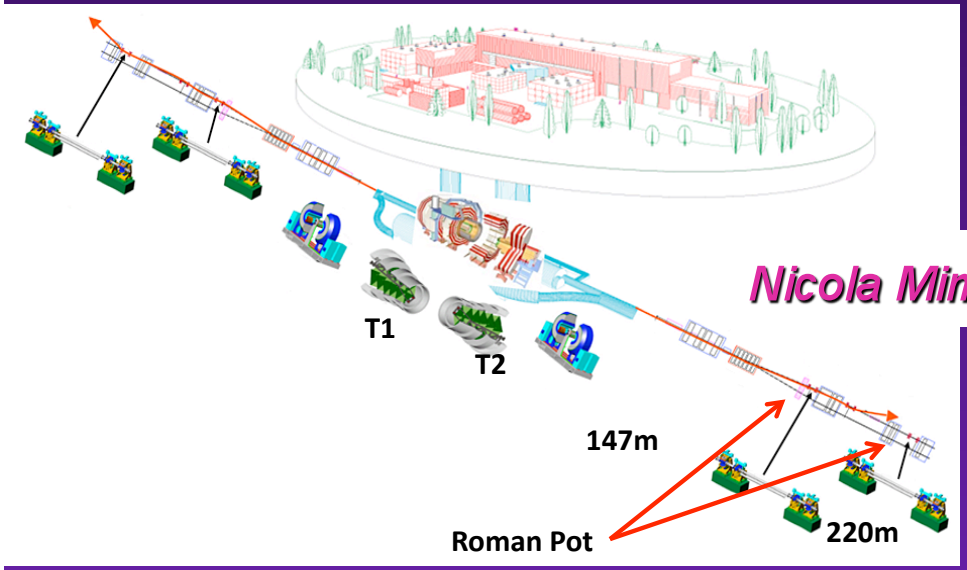
  - **Transverse imaginary effective impedance (dip + quad):**

PREDICTION	MEASUREMENT
• **7 TeV: ~ 25-30 MΩ/m**	• **?**

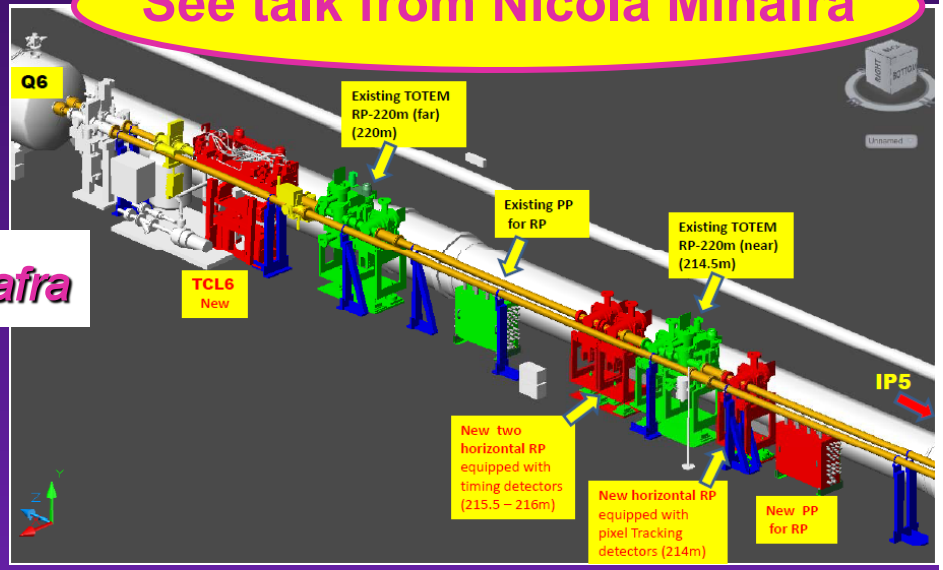
Meas. at 3.5 and 4 TeV revealed a factor ~ 2 higher than predicted

IMPEDANCES OF THE TOTEM RPs (1/3)

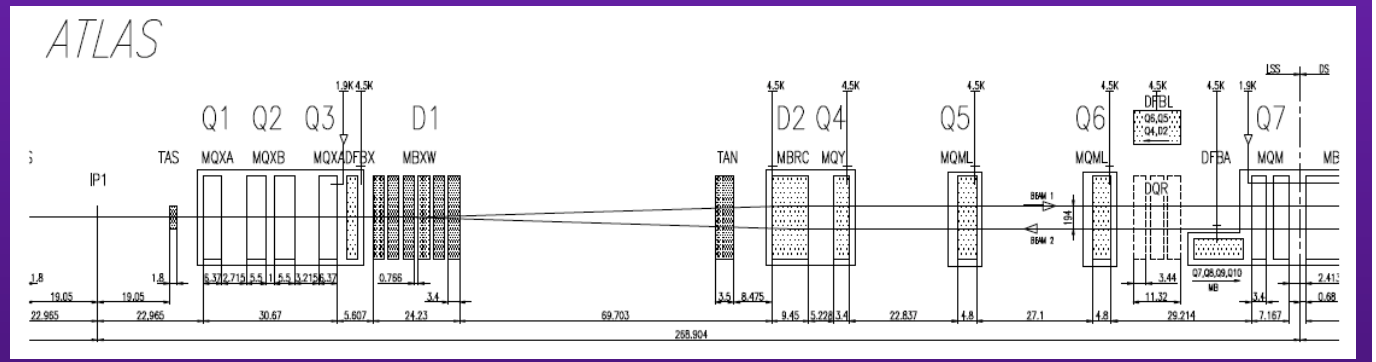
See talk from Nicola Minafra



Nicola Minafra



- # of RPs in 2012
  - 2 stations at 147 m and 2 stations at 220 m
  - 2 V + 1 H / station
- # of RPs > LS1
  - 4 stations at 220 m: 8 V + 4 H
  - + 1 or 2 new H ones (cylindrical)
- # of RPs for high-intensity runs: 3 or 4 max



- New RP with timing detector, too big for current RP
  - Rotate current RP
  - Make a new cylindrical RP

IMPEDANCES OF THE TOTEM RPs (2/3)

Nicola Minafra

- Results for 1 RP with the beam at 1 mm

	$Z_{\parallel}^{eff}/n$ (mΩ)	% to total LHC current impedance (90 mΩ)	$\bar{Z}_{\perp}^{eff}$ (KΩ/m)	% to total LHC current impedance (25 MΩ/m)	Heating (W)
Present RP [1]	1.7	1.9%	80	< 0.3%	62
Rotated RP [2]	2.6	2.9%	20	< 0.1 %	241
Cylindrical RP [3]	1.1	1.1%	50	< 0.2 %	13
Cu shielded RP [4]	1.2	1.3%	70	< 0.3 %	10

Imaginary part

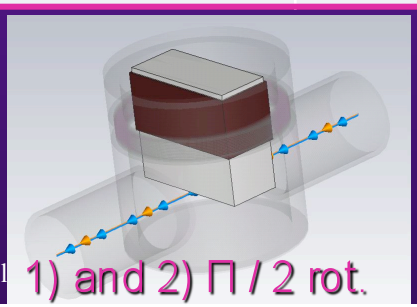
Imaginary part

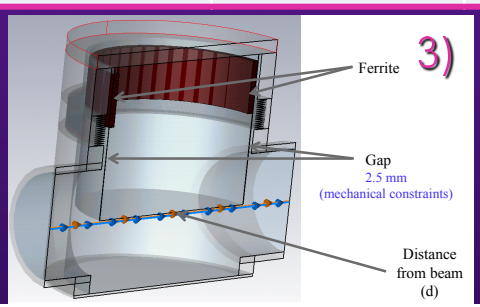
35% better

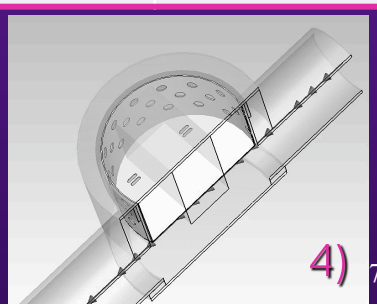
~ × 5 better

30% better

~ × 6 better



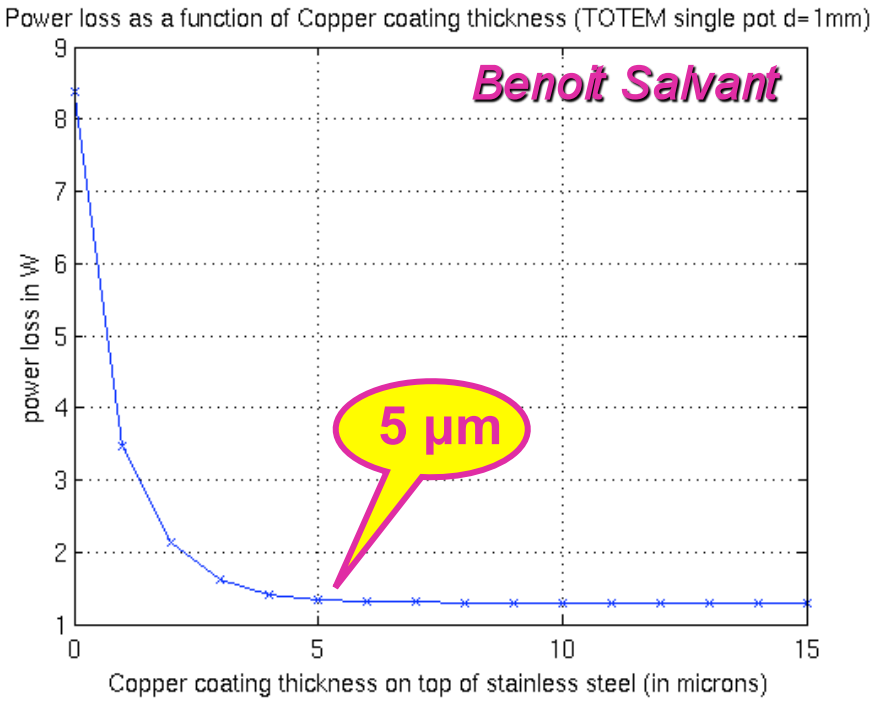


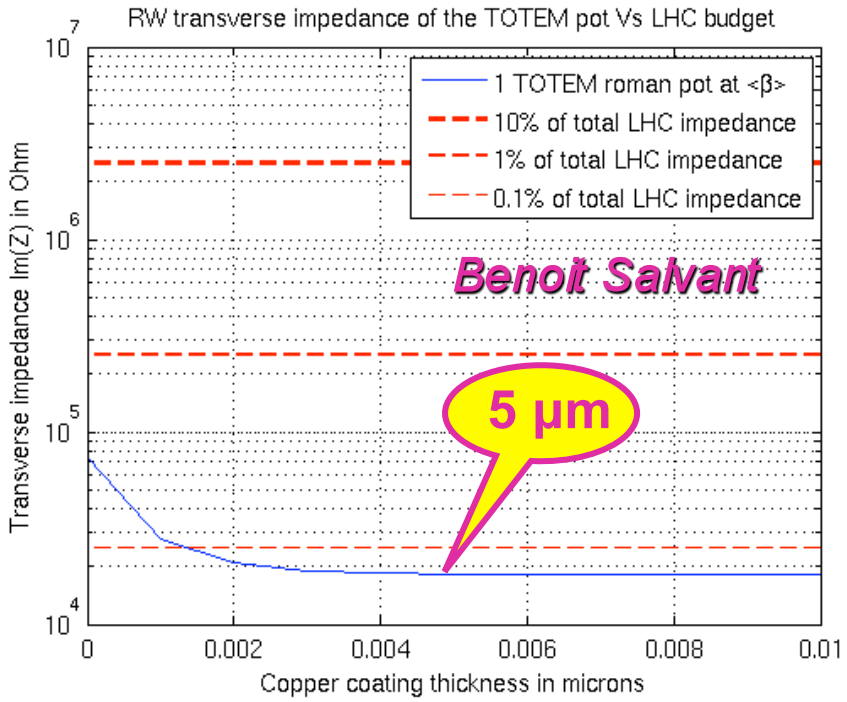


IMPEDANCES OF THE TOTEM RPs (3/3)

- **Studies of Cu coating thickness for the Resistive-Wall part**
  - 3 layers (NEG 1.5 µm + Copper + infinite stainless steel)
  - Only 1 RP on one side (horizontal) at 1 mm distance to the beam
  - Computations for nominal Gaussian beam (25 ns and 1.15E11 p/b)

=> > ~ 5 µm is OK (10 µm recommended if possible)





CONCLUSION

- 3 or max 4 H RPs for high-intensity runs => Should be OK but depends also on all the other impedance contributors => Imagine 10 impedance contributors each increasing by 5%... The other equipments linked to the RPs need to be also considered (collimators, etc.)
- Detailed heat transfer studies to be done with the ferrite
- Recommended Cu coating for the Resistive-Wall impedance: > ~ 5 µm is OK (10 µm if possible)
- EM simulations based on several assumptions => Measurements on a prototype should be performed as a final check / validation!

ACKNOWLEDGEMENTS

- Many thanks to Nicola Minafra for all his nice studies over the past few months with Benoit Salvant and the impedance team
- A lot of collaboration with ALFA which was very positive and useful