Status of Collimator Transverse Impedance Measurements

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Collimation Working Group Meeting

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Acknowledgments

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For their help, support and advice in setting up the experiment !

Agenda

- Context
- Objectives
- Methods and Results
- Outlook and Perspectives

Context (1/2)

- Transverse impedance of LHC has to be minimized to prevent the onset of instabilities (especially the real part)

Total transverse impedance budget for LHC: $$Z_{\perp} = 100 \text{ M}\Omega/\text{m}$$

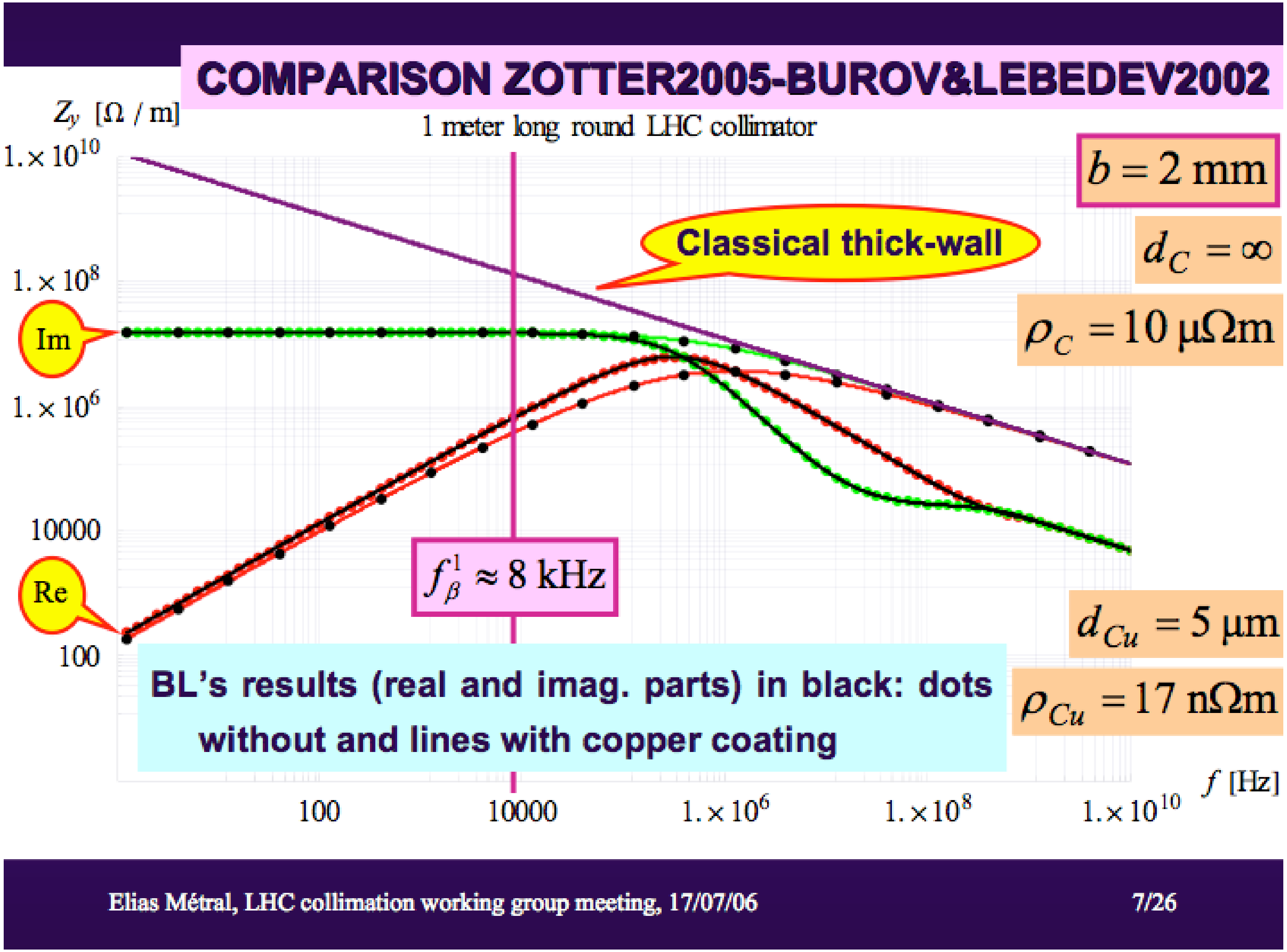
- At low frequencies (f<1 MHz), impedance measurements and simulations are more difficult to perform.

- Classical thick wall theory predicts :

$$Z_{\perp}(f) \propto \frac{1}{\sqrt{f}}$$ and ***<u>for one collimator</u>*** $$\text{Re}[Z_{\perp}(8\text{ kHz})] > 100 \text{ M}\Omega/\text{m}$$

- But, using analytical calculations with less approximations…

Context (2/2)



Can we believe newer theories from Zotter/Métral and Burov/Lebedev?

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Objectives for Collimation Working Group

- Assess the transverse impedance of collimators at low frequencies with simulation and/or measurements
- Can the LHC beam be stable with collimators?
- Support the design for phase II collimation system

This presentation is an update, studies are still ongoing

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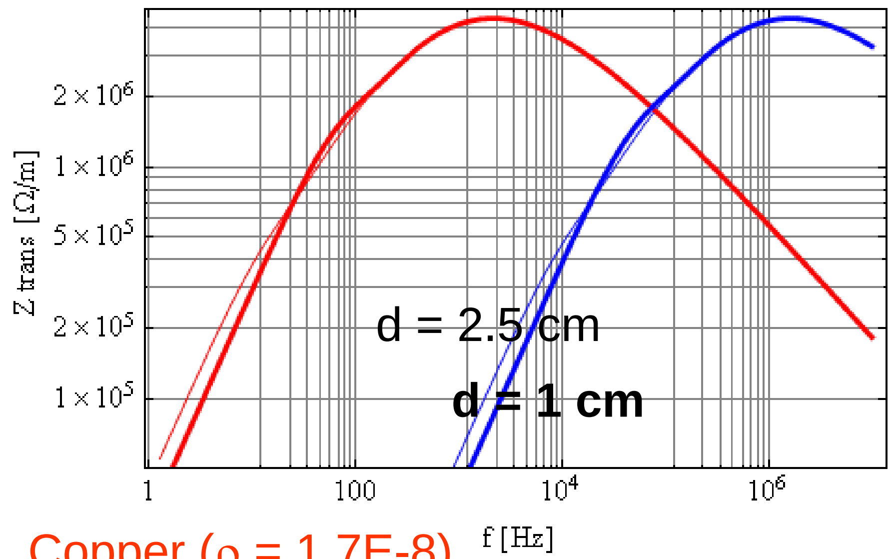
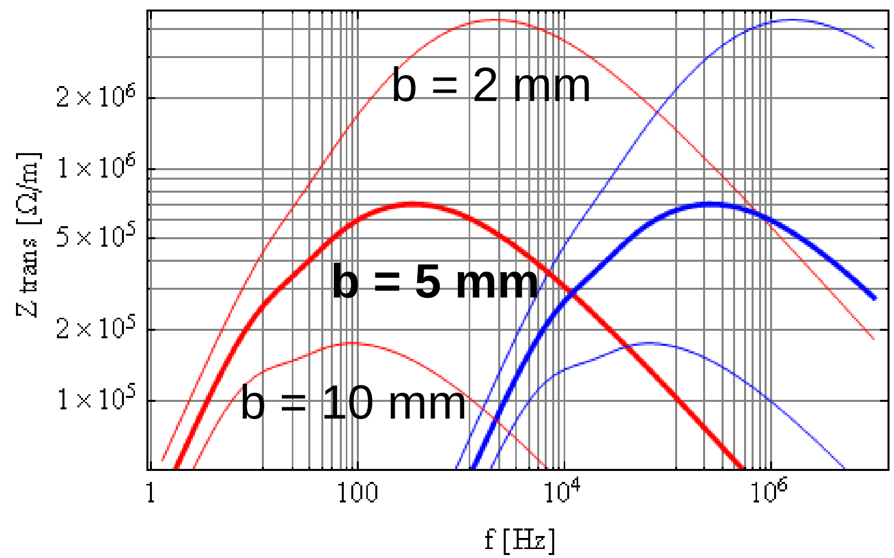
Theory

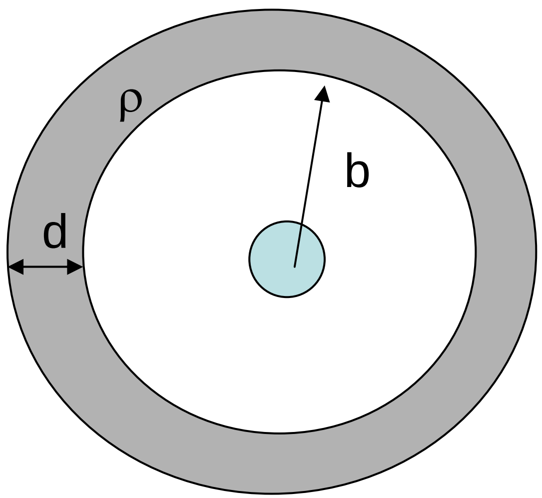
- Cylindrical monolayer pipe
- Resistive Wall impedance
- Variables:
  - b : half gap of the beam pipe
  - d : thickness of the beam pipe
  - ρ : resistivity of the beam pipe



Copper (ρ = 1.7E-8)

Graphite (ρ = 1.3E-5)





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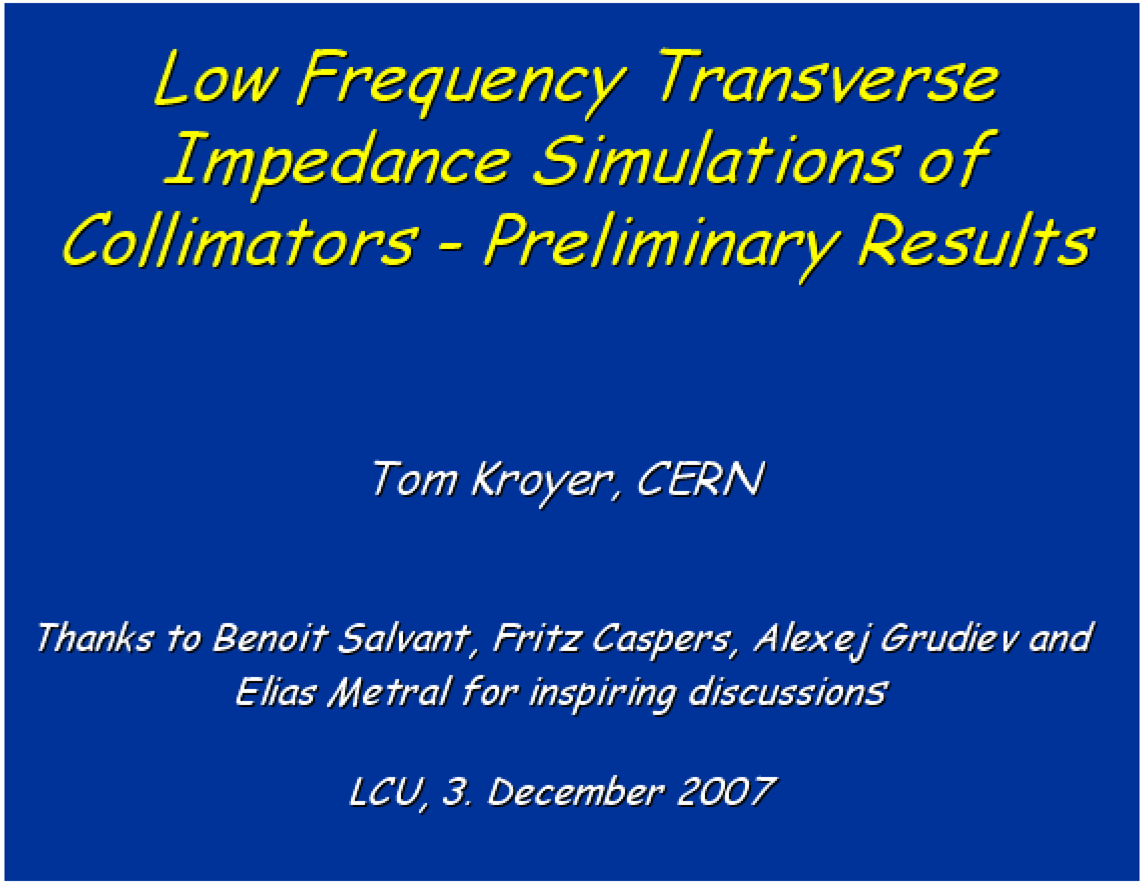
FEA Simulations

Tom’s presentation at the LCU meeting on 03/12/2007



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Bench Measurements : probe coil method

- Nassibian and Sacherer (Nucl. Instrum. Methods 159 (1979) 21-7):

  Transverse beam impedance related to the impedance of a loop

For a strongly coupled coil of N turns and width Δ :

$$Z_{trans} = \frac{c}{\omega} \frac{Z_{coil}}{N^2 \Delta^2}$$

- Where
  - The Electric field is neglected in the Wake force calculation
  - Δ is the width of the coil

- Need to use a reference of the same geometry to suppress the space charge impedance and to try to avoid unwanted effects:

$$Z_{trans}^{Graphite} = \frac{c}{\omega} \frac{Z_{coil}^{Graphite} - Z_{coil}^{\mathrm{Reference}}}{N^2 \Delta^2}$$

F.Caspers, A.Mostacci,L.Vos http://lhcp.web.cern.ch/lhcp/LCC/LCC_2002-01.htm#main3a

F.Caspers, A.Mostacci, U.Iriso

Bench Measurements of Low Frequency Transverse Impedance, CERN-AB-2003-051-RF

Bench Measurements : Copper as reference?

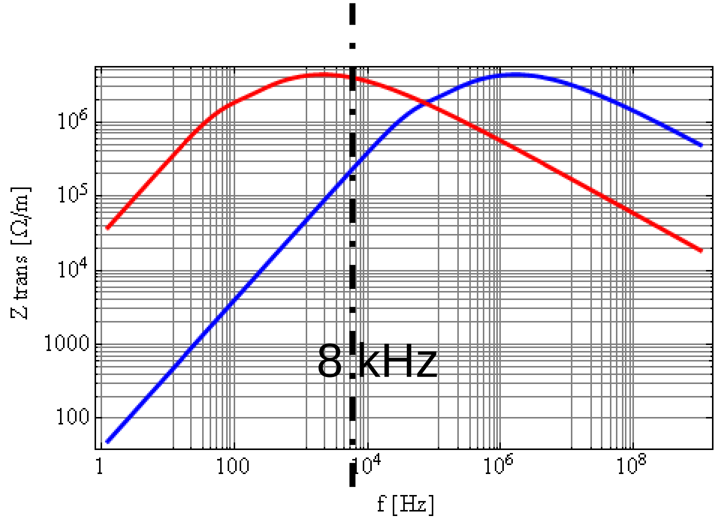
- Ideally, need a perfect conductor for reference, however:

- Analytical calculations:

  Copper (ρ = 1.7E-8)

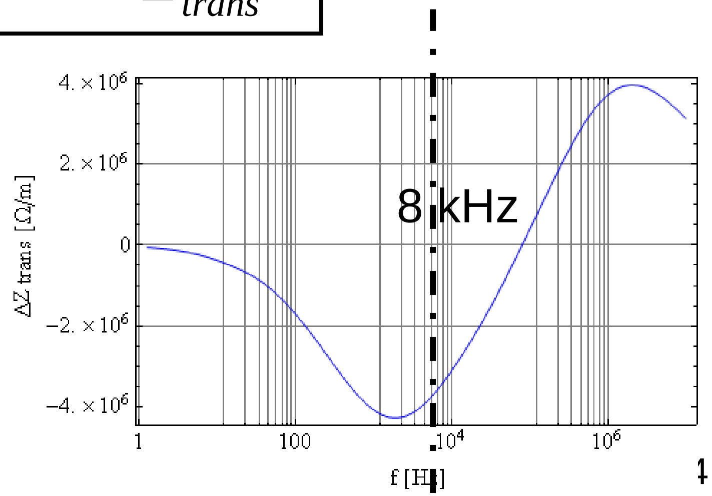
  Graphite (ρ = 1.3E-5)

$$\Delta Z_{trans} = \frac{c}{\omega} \frac{Z_{coil}^{Graphite} - Z_{coil}^{Copper}}{N^2 \Delta^2}$$



- So, at low frequencies (f < 0.1 MHz),

$$Z_{trans}^{Graphite} > Z_{trans}^{Copper}$$



- Therefore, in the absence of adequate reference,
  we keep ΔZtrans

Bench Measurements: instruments

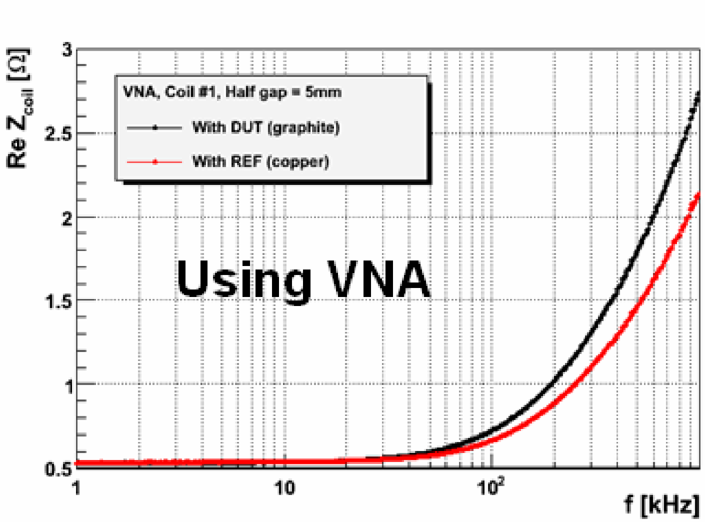
- 2 different instruments were used:

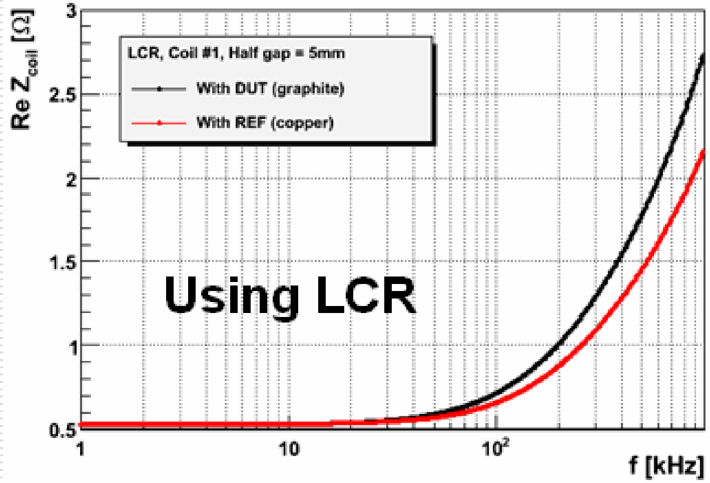
VNA (10 Hz → 500 MHz)

LCRmeter (20 Hz → 2 MHz)

Bench Measurements: choosing the instrument

Example of measured signals: **real part of coil impedance in the presence of copper and graphite**

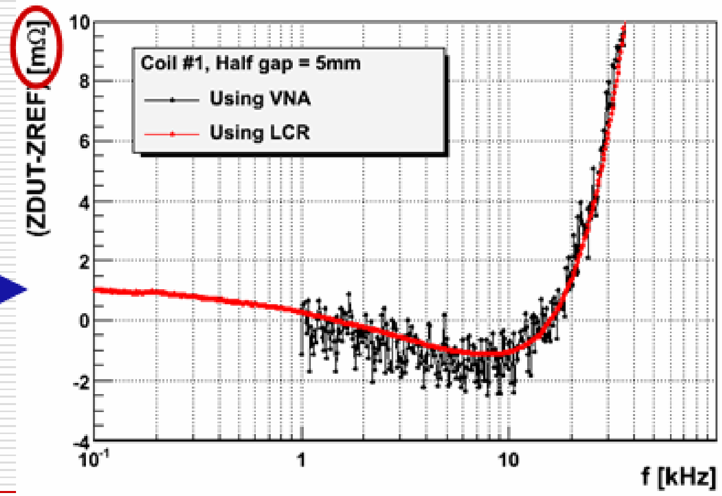




Looking at the difference

ZDUT-ZREF at low frequencies:

noise may become ~ =signal !



F.Roncarolo - LCU - 3-Dec2007

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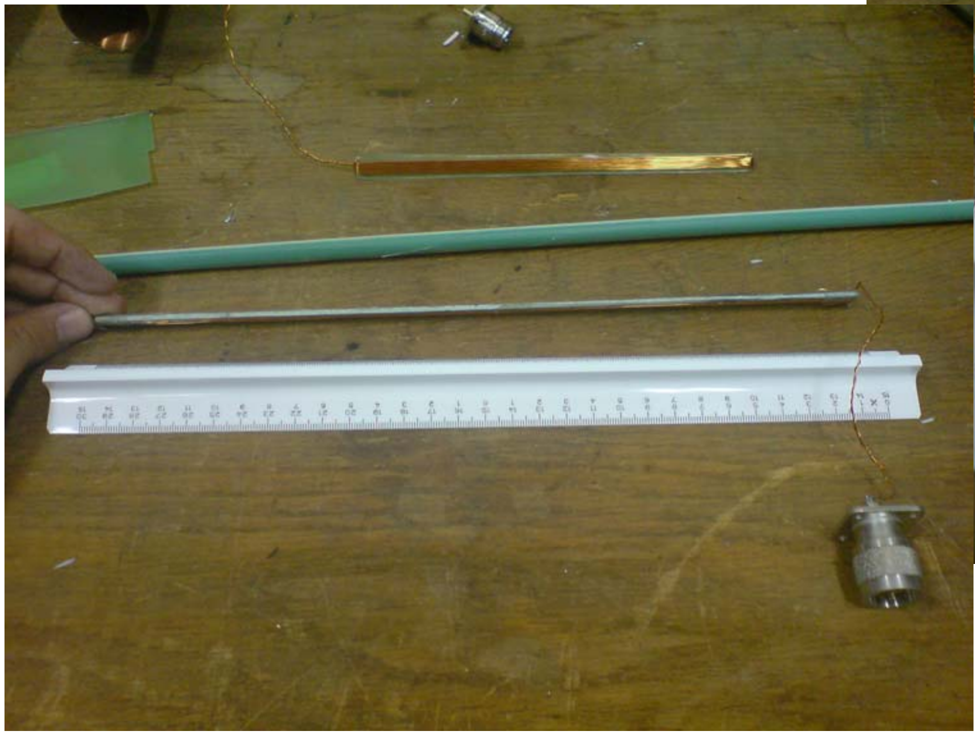
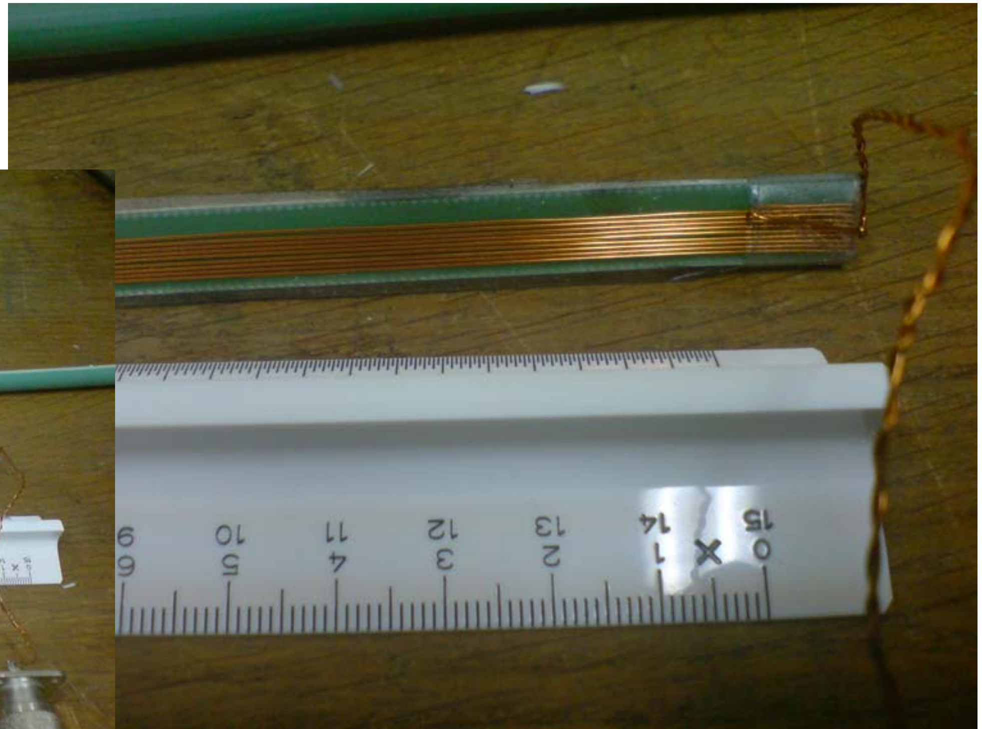
Therefore, in these conditions, LCRmeter is less noisy than the VNA.

Bench Measurements : Coils

- Home made coils…



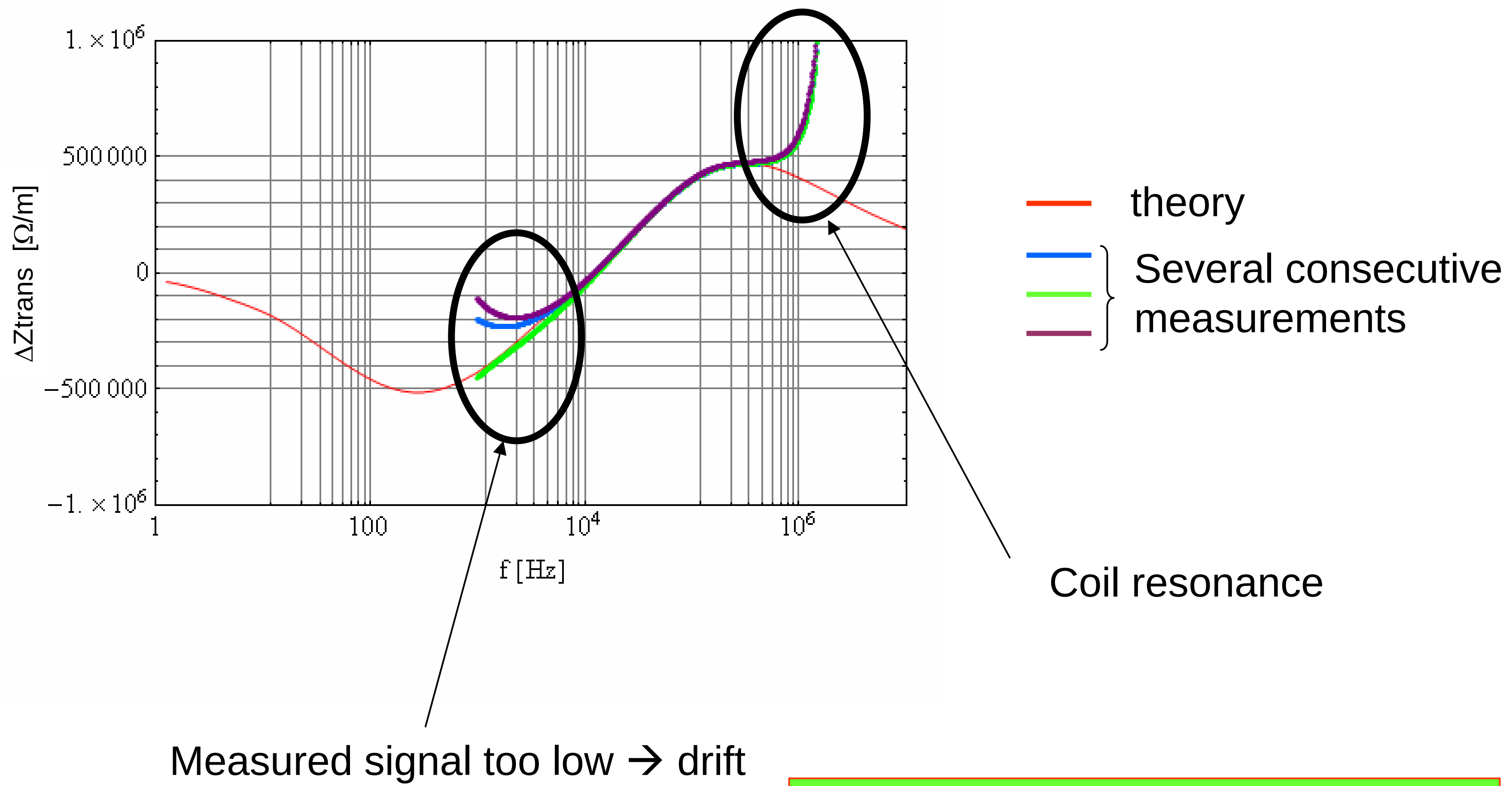


Thin coils to measure small gaps → issue with **mechanical stability**
→ small coil width → **small signal**

More turns → **higher signal**
→ but also **lower resonance of the coil**

Bench Measurements : Coils

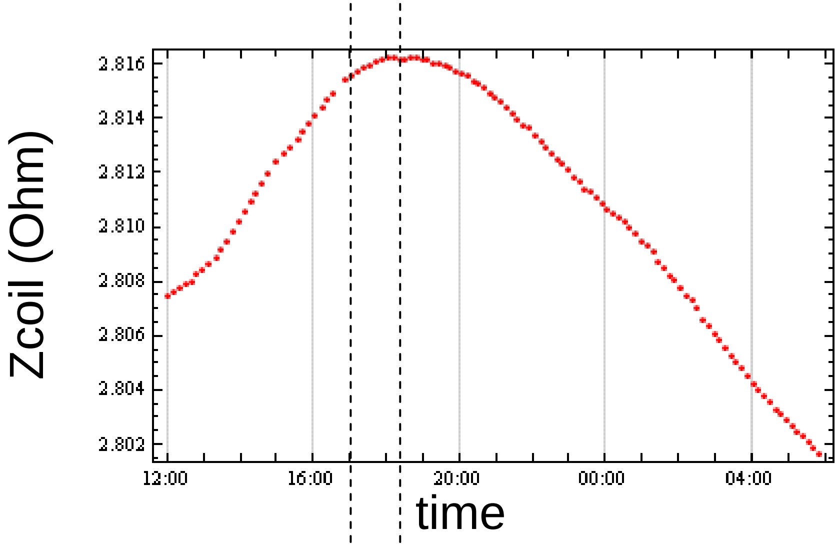
- Example of measurement of $\Delta Z_{trans} = Z_{trans}^{Graphite} - Z_{trans}^{Copper} = \frac{c}{\omega} \frac{Z_{coil}^{Graphite} - Z_{coil}^{Copper}}{N^2 \Delta^2}$

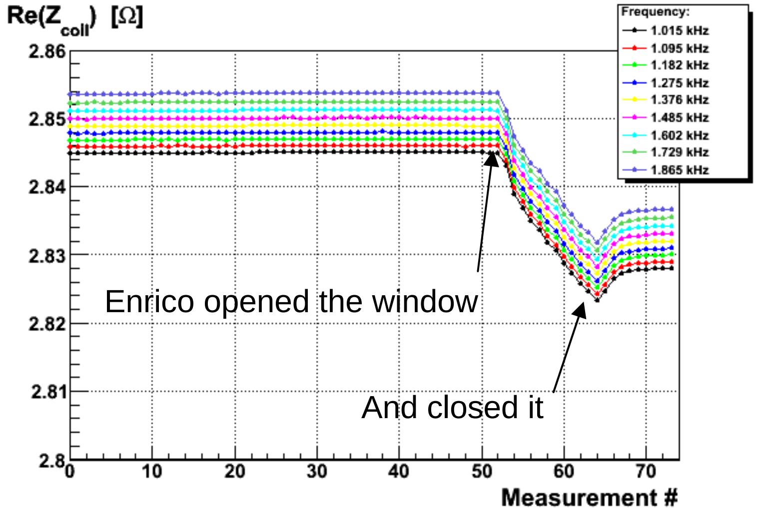


Where does this drift come from????

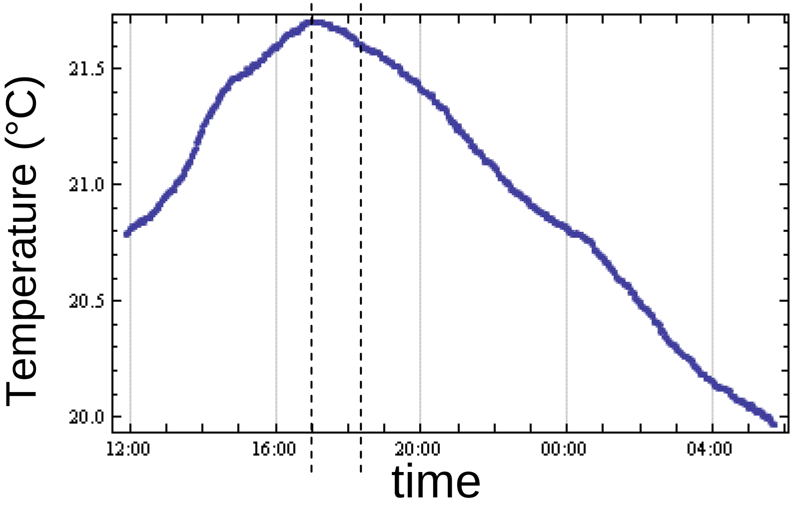
Bench Measurement drift: impact of temperature

- Observation of the drift of the impedance at 1 kHz with time



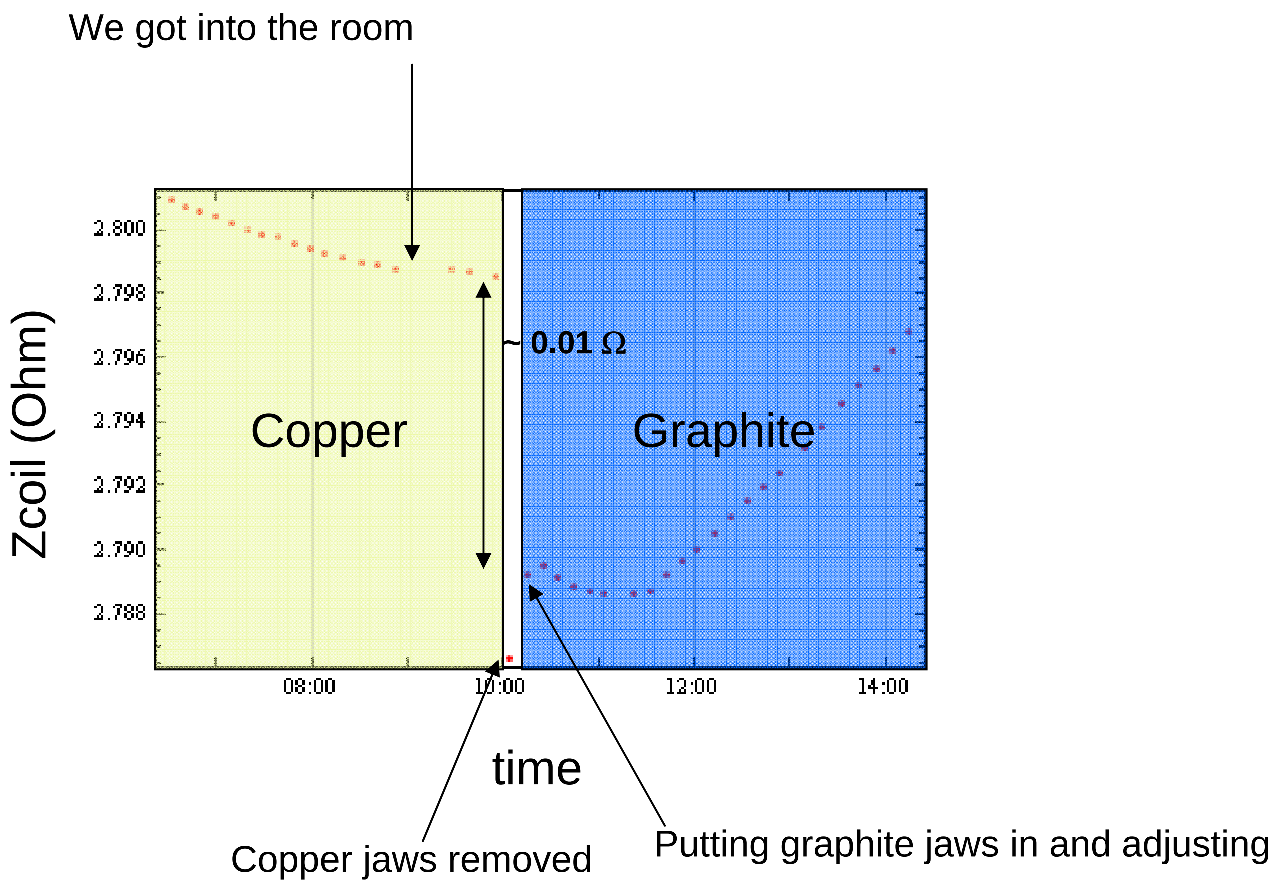


- Observation of the drift of temperature in a temperature controlled room (Bldg



Bench Measurement drift: impact of temperature

- Does this drift matter? Unfortunately, it does…
- Continuous measurements (every 10 minutes) at 1 kHz, in the AT/MEI magnet measurement room (Bldg 867 temperature controlled at +/- 1°C)



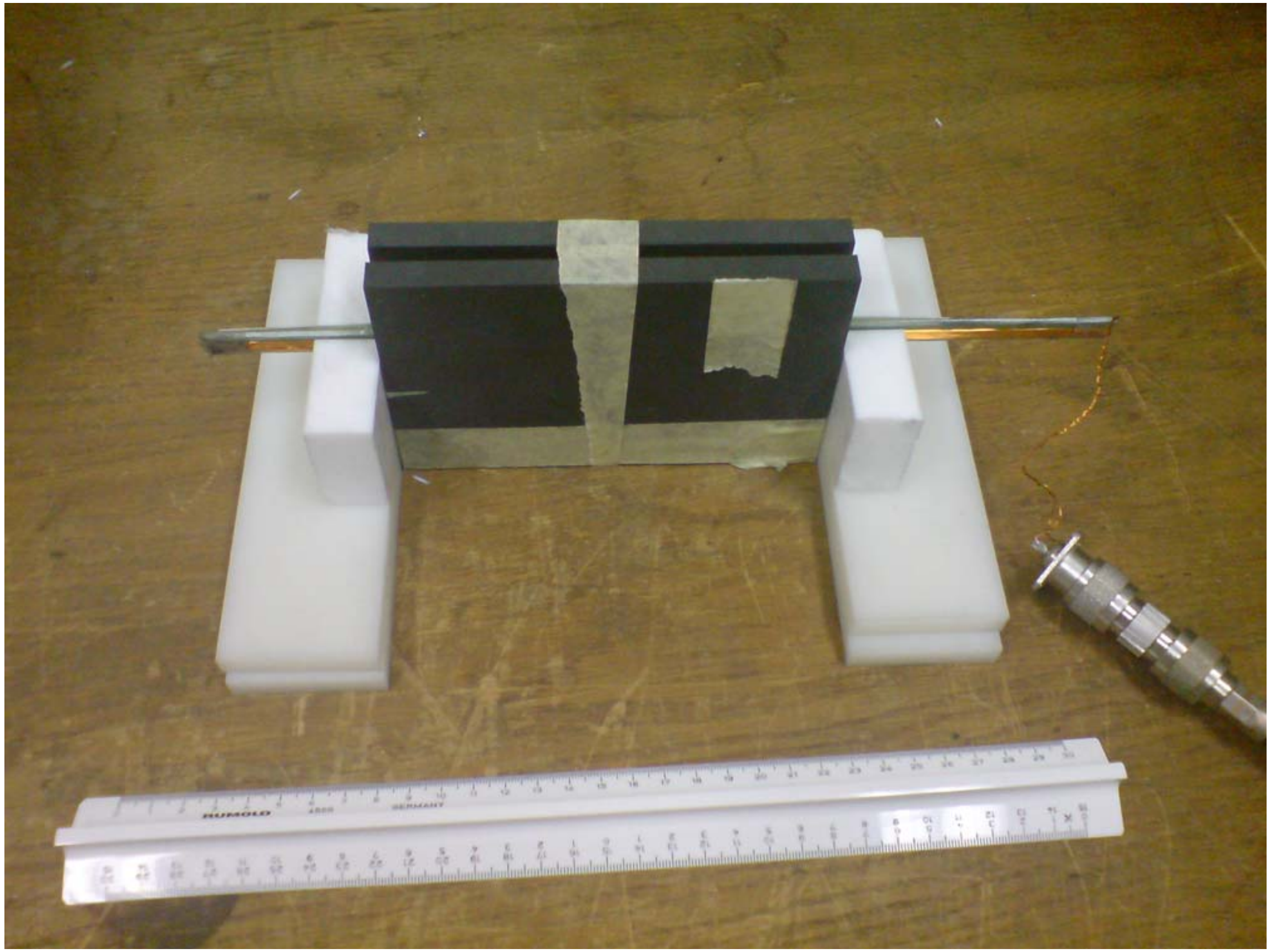
Therefore, need for a room with much tighter temperature regulation!!! → PS magnet 101 reference room

Bench Measurements: planning

- 1st step
  - Measurement of the impedance of small plates (15 cm * 10 cm * 1 cm)
- 2nd step
  - Measurement of the impedance of collimator jaws (120 cm * 10 cm * 2.5 cm)
- 3rd step
  - Measurements of the impedance of a full collimator

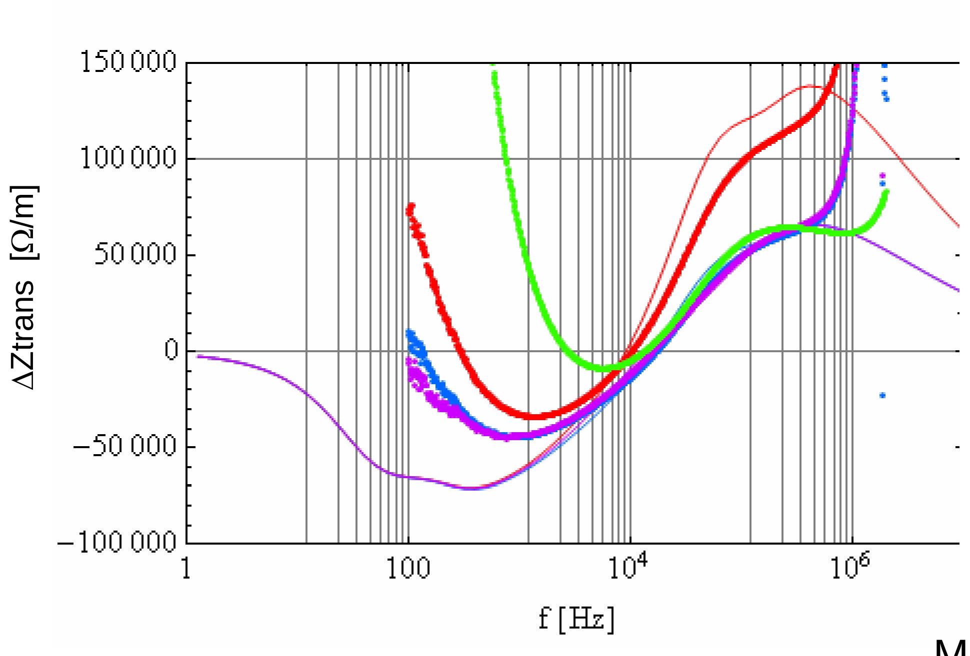
Bench Measurements: 1) small plates

- Measurement of the impedance of small plates (15 cm * 10 cm * 1 cm)

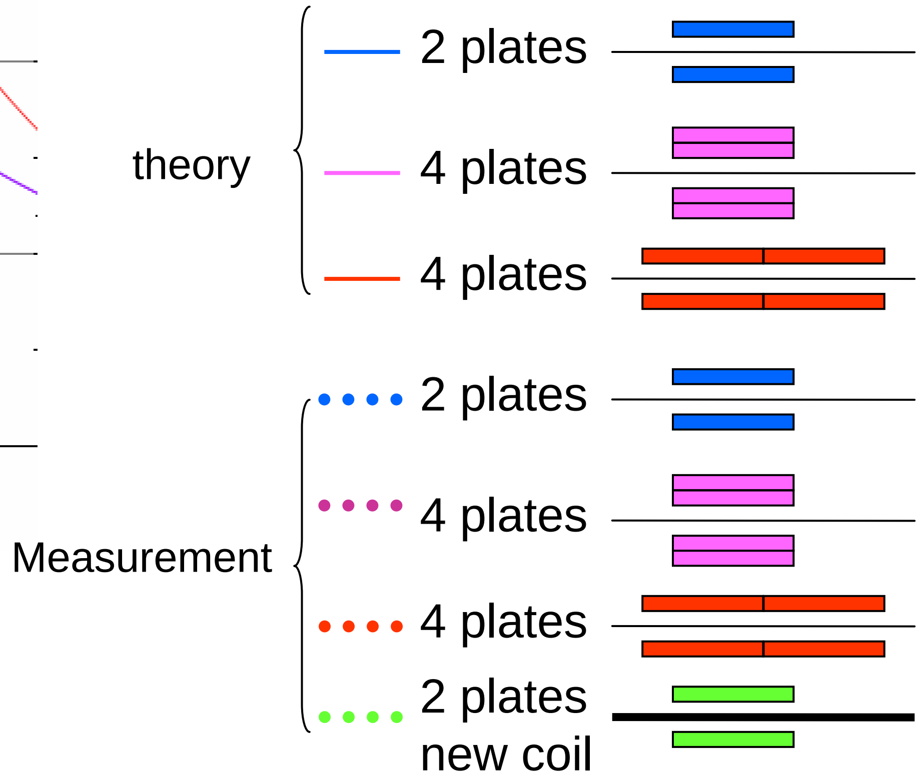


Bench Measurements: 1) small plates

- Measurement of the impedance of small plates (15 cm * 10 cm * 1 cm)



Half gap = 5 mm



Temperature was not controlled at the time…

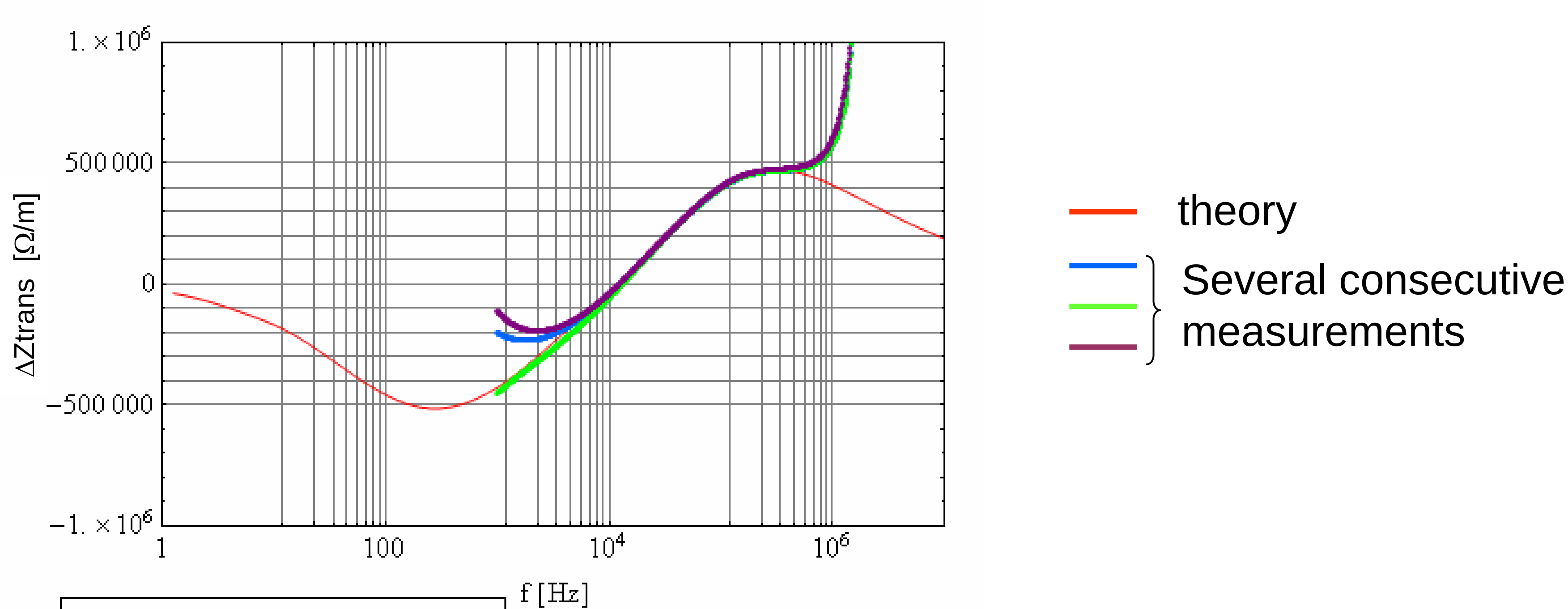
…actually the setup stood rigth next to the window

Bench Measurements: 2) collimator jaws

- Measurement of the impedance of collimator jaws (120 cm * 10 cm * 2.5 cm)

Bench Measurements: 2) collimator jaws

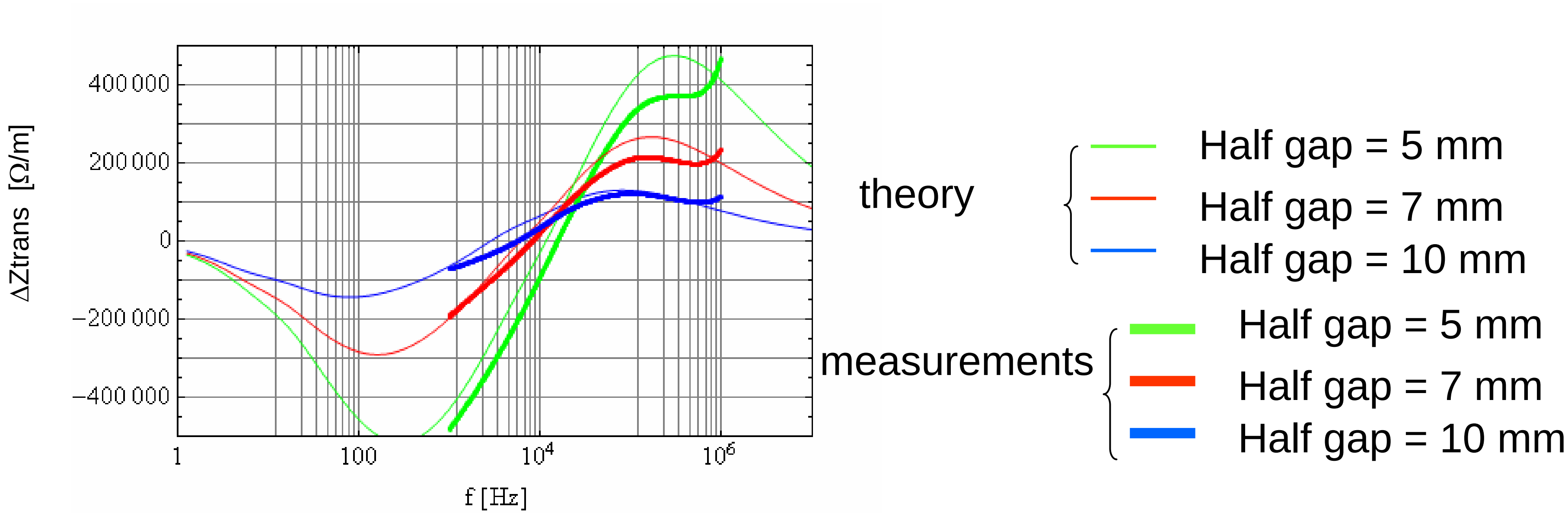
- Measurement of the impedance of collimator jaws (120 cm * 10 cm * 4 cm) borrowed from Oliver Aberle (graphite used for TCDI, copper are spare)



Half gap = 5.25 mm
Coil width = 3.5 mm
Coil made of 11 turns

Bench Measurements: 2) collimator jaws

- Bonus: Quick and dirty scan in half gap performed on Friday 01/02/08 evening. Temperature was controlled but the alignment was not perfect.



Coil width = 3.5 mm
Coil made of 11 turns

Bench Measurements: 3) full collimator

How could we measure it best on a full collimator?

- Gap is so small, that touching the surface is unavoidable.
- Thin long coil easily bends when not vertical→ need for a horizontal collimator
- Being able to insert the coil from above would be of great help, and would prevent scratches on the collimator
- Controlled temperature is important to compare to the reference
- Which reference? Copper jaws ? Air?

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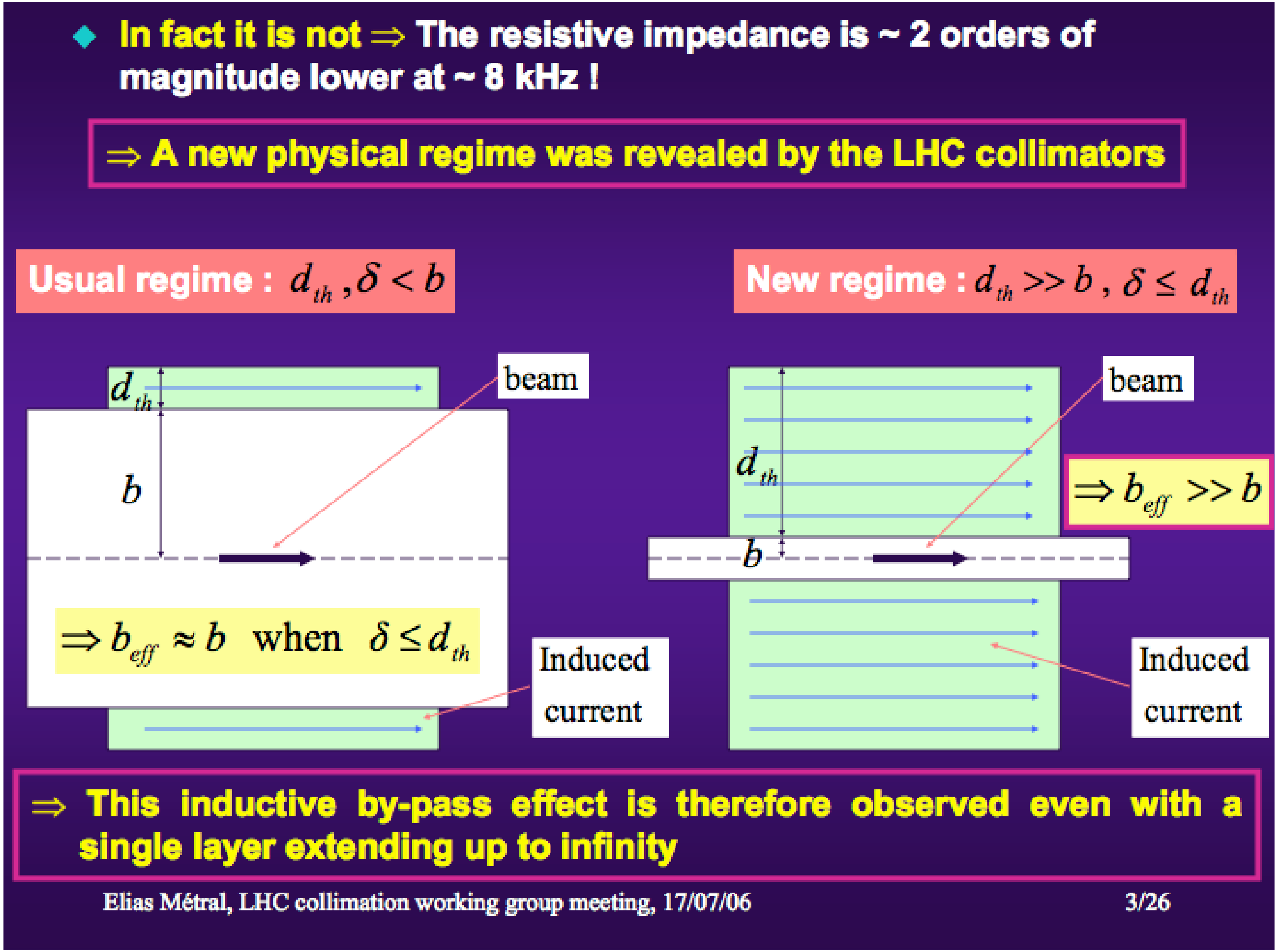
Outlook and perspectives

- Agreement between Zotter-Burov-Lebedev theory, measurement and simulations for the low frequency part of the real transverse impedance
- For a 1.2 m long collimator, 2 mm half gap,

  Re[Zy(f = 8 kHz)] ~ 400 kΩ/m
- Still some work remains to improve accuracy, and reduce alignment errors
- The impedance Re(*Z(f))* has a maximum that depends on the material and the thickness

  → opportunity to use composite materials to optimise the impedance in different frequency ranges
- Let’s measure the collimator!

Context (2/3)



In fact it is not ⇒ The resistive impedance is ~ 2 orders of magnitude lower at ~ 8 kHz !
⇒ A new physical regime was revealed by the LHC collimators
Usual regime : $d_{th}, \delta < b$
New regime : $d_{th} >> b$, $\delta \leq d_{th}$
d_{th}
b
beam
$\Rightarrow b_{eff} \approx b$ when $\delta \leq d_{th}$
Induced current
d_{th}
b
beam
$\Rightarrow b_{eff} >> b$
Induced current
⇒ This inductive by-pass effect is therefore observed even with a single layer extending up to infinity
Elias Métral, LHC collimation working group meeting, 17/07/06
3/26