Status of the LHC dump kicker low frequency impedance evaluation

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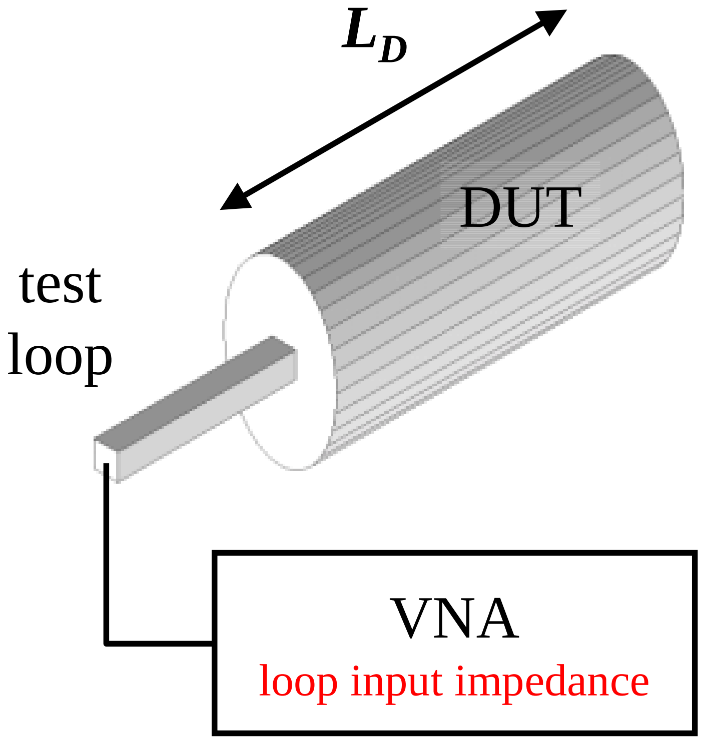
- Transverse impedance measurement set-up.
- A reference case: circular steel pipe.
- Dump kicker: bypass effect on the long. imp.
- Dump kicker: trans. imp. coil measurements.
- Dump kicker: displaced wire.

Measurement set-up



L_D

DUT

test loop

VNA

loop input impedance

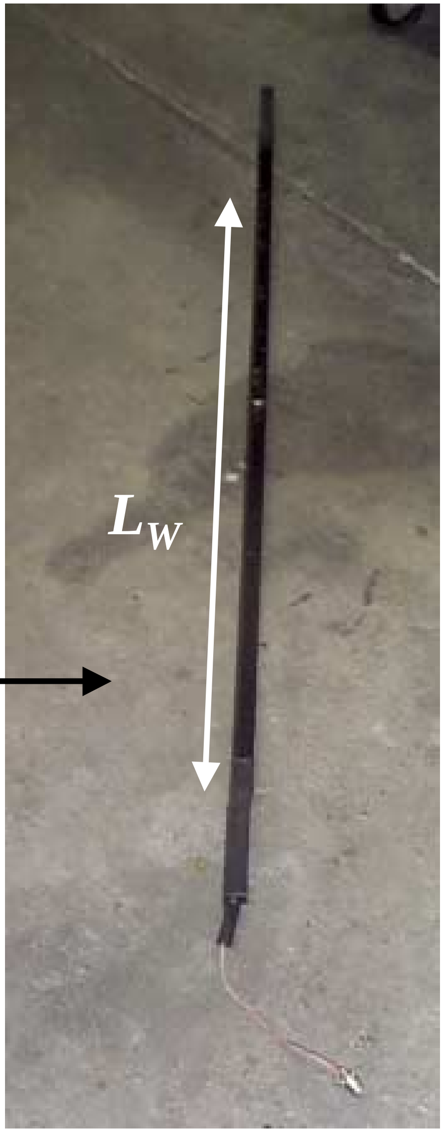
Δ loop width

N # turns

$L_W = 1.25$ m

$\Delta = 22.5$ mm

$N = 10$

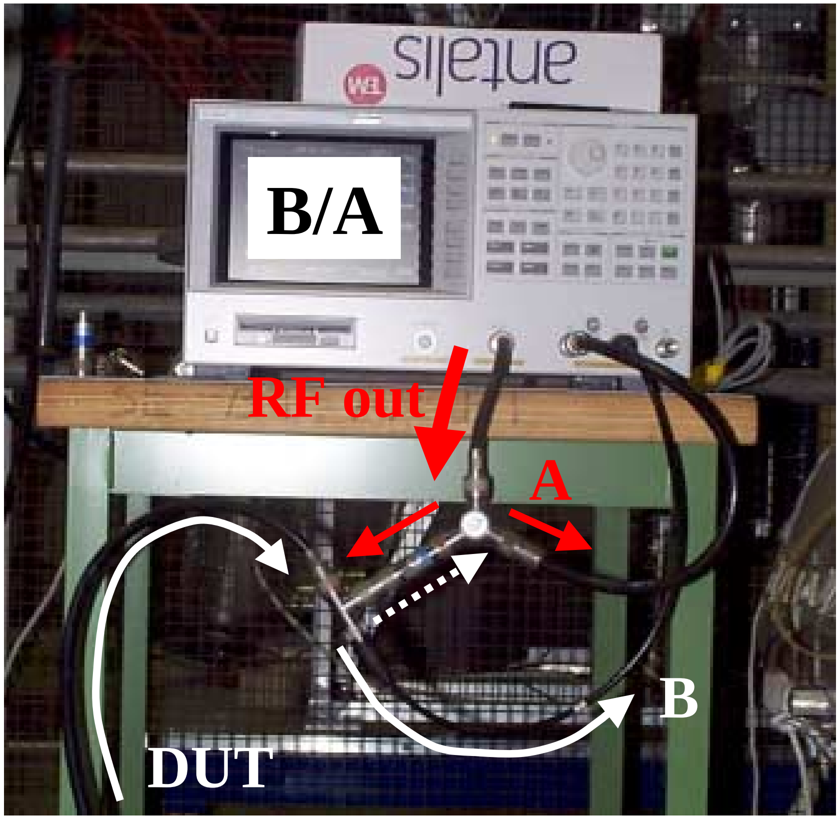


$$Z_T = \frac{c}{\omega} \frac{Z^{DUT} - Z^{free}}{N^2 \Delta^2}$$

added loop impedance

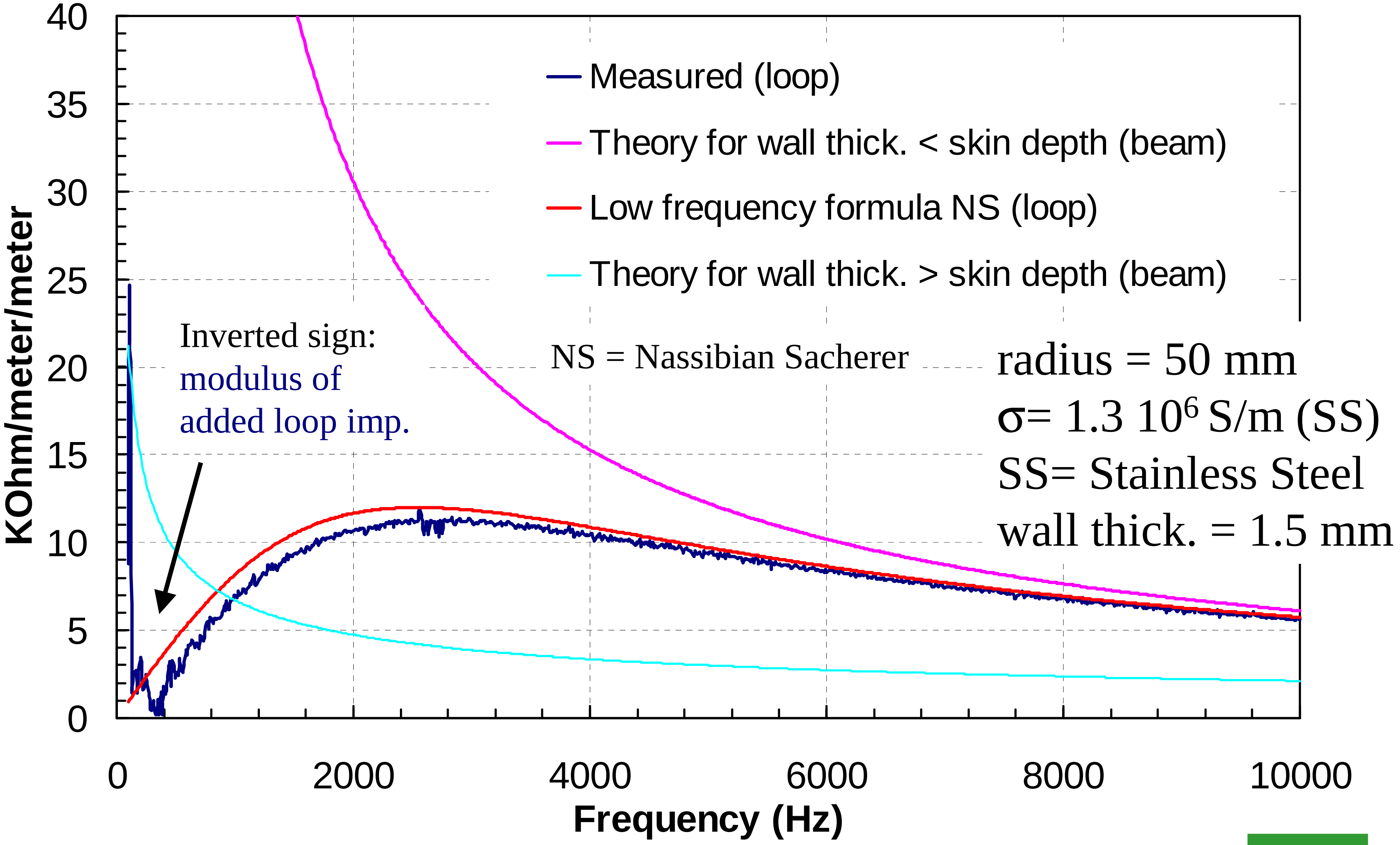
Two different network analyzer set-ups

To measure the added loop impedance, two different S-parameters test sets are used, according to the frequency range. The DUT has an impedance much smaller than 50 Ohm.



1. **Resistive coupling network**
   100 Hz – 10 kHz (IF-BW=30 Hz)
2. **Transformer type dir. coupler**
   10 kHz – 1 MHz (IF-BW=100 Hz)

Re {trans. imp. per unit length}: circular pipe

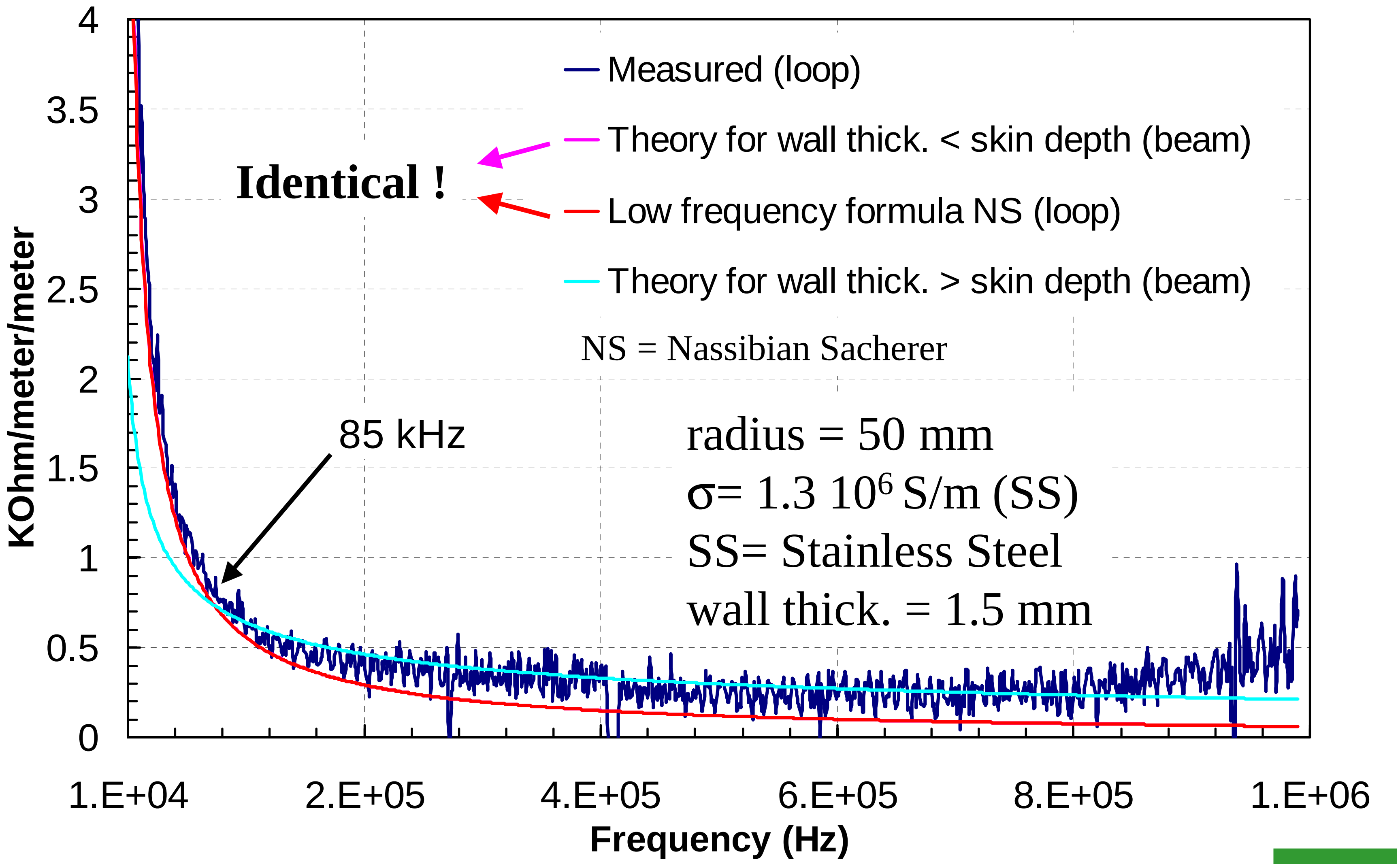


Inverted sign:
modulus of
added loop imp.

NS = Nassibian Sacherer

radius = 50 mm
σ= 1.3 10^6 S/m (SS)
SS= Stainless Steel
wall thick. = 1.5 mm

Re {trans. imp. per unit length}: circular pipe



Identical !

85 kHz

NS = Nassibian Sacherer

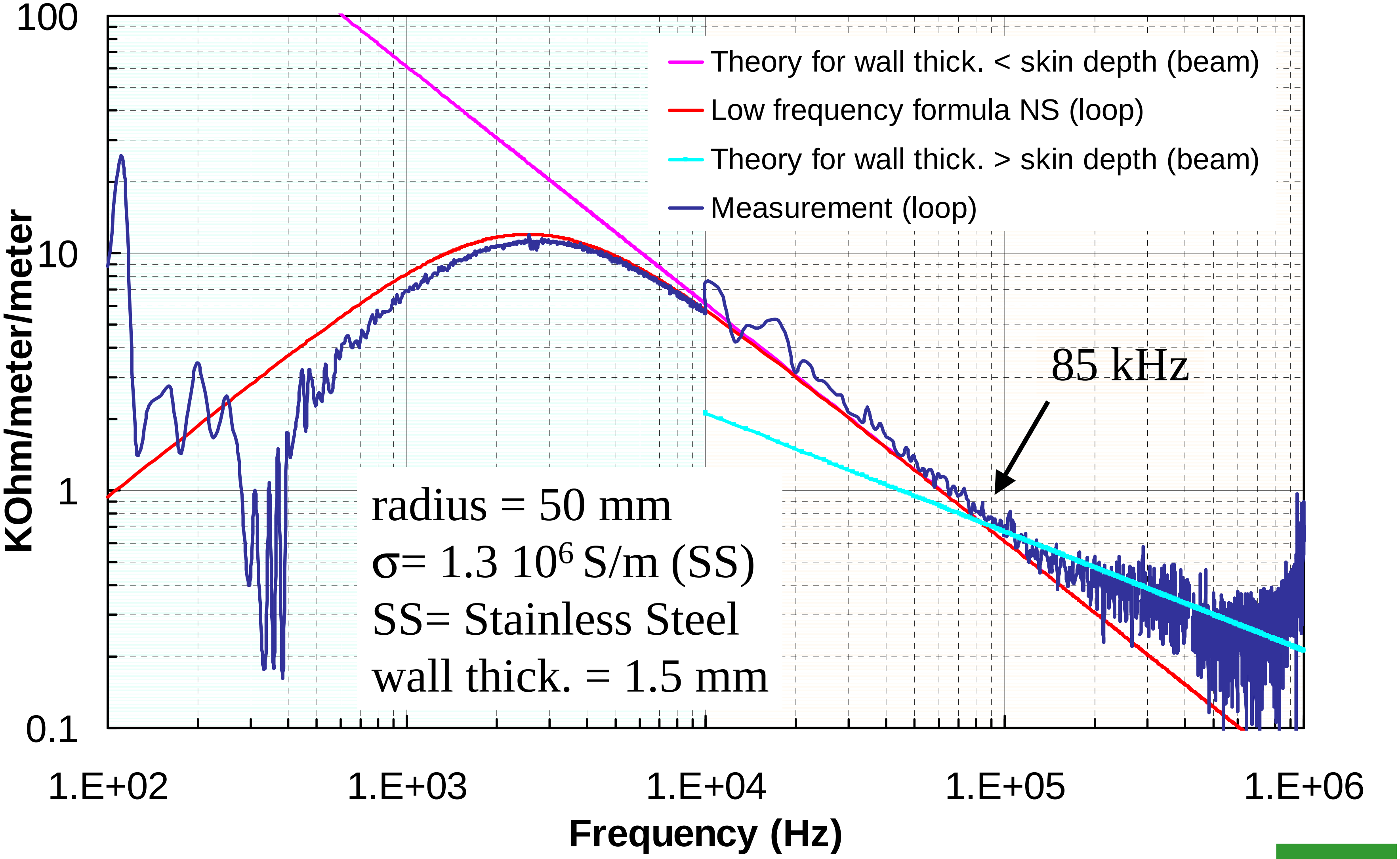
radius = 50 mm

σ= 1.3 10^6 S/m (SS)

SS= Stainless Steel

wall thick. = 1.5 mm

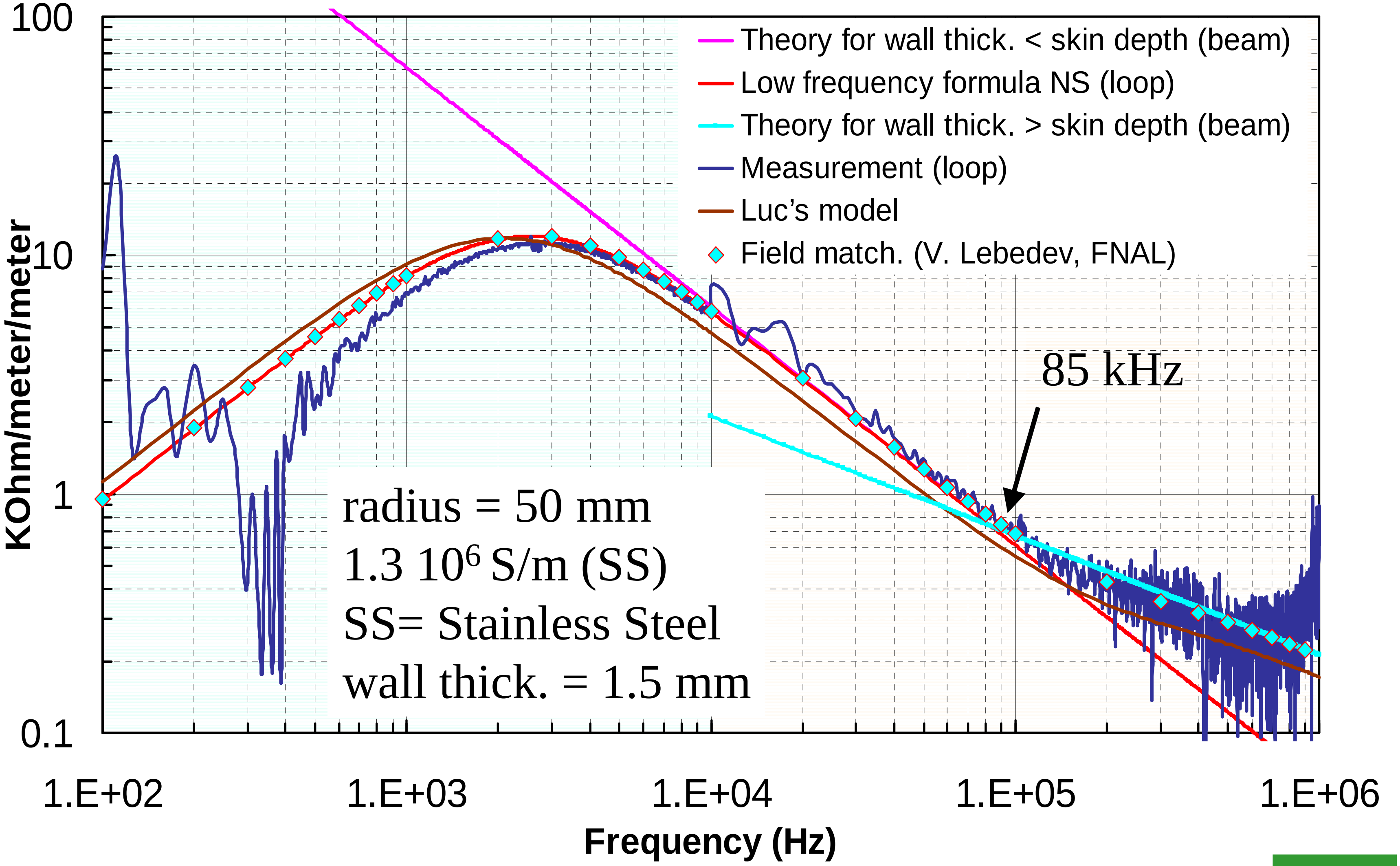
Re {trans. imp. per unit length}: circular pipe



85 kHz

radius = 50 mm
σ= 1.3 10^6 S/m (SS)
SS= Stainless Steel
wall thick. = 1.5 mm

Re {trans. imp. per unit length}: circular pipe



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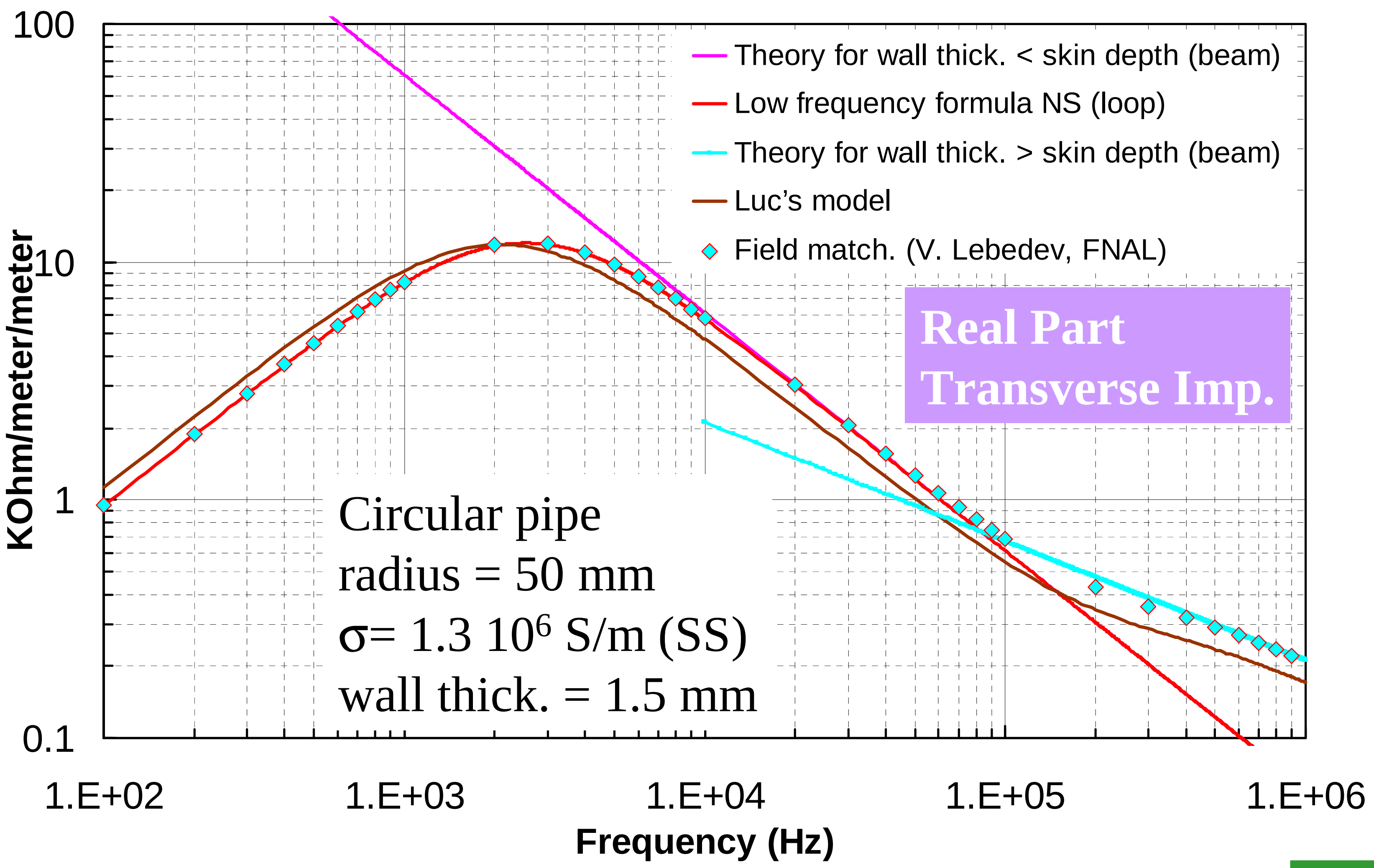
From theory …



Circular pipe
radius = 50 mm
σ= 1.3 10^6 S/m (SS)
wall thick. = 1.5 mm

Used formulae: circular pipe

$$\frac{Z_T}{L} = \frac{1+j}{2\pi}\mu_r \frac{Z_0\delta}{b^3}$$ $\delta \ll d$ (thick wall)

$$\frac{Z_T^{Re}}{L} = \frac{c}{\pi\, b^3\, \sigma\, \omega\, d}$$ $\delta \gg d$ (thin wall)

b	radius
d	wall thickness
σ	wall conductivity
L	device length
δ	skin depth

Nassibian Sacherer

$$Z_T = \frac{c}{4\omega b^2}\,\frac{R_W - j\omega L_W}{1+(\omega_c/\omega)^2}$$

$$\omega_c = \frac{R_W}{L_W} \qquad R_W = 8\,\frac{L}{2\pi\, b\, d\, \sigma} \qquad L_W = \frac{2\mu_0\mu_r}{\pi}L$$

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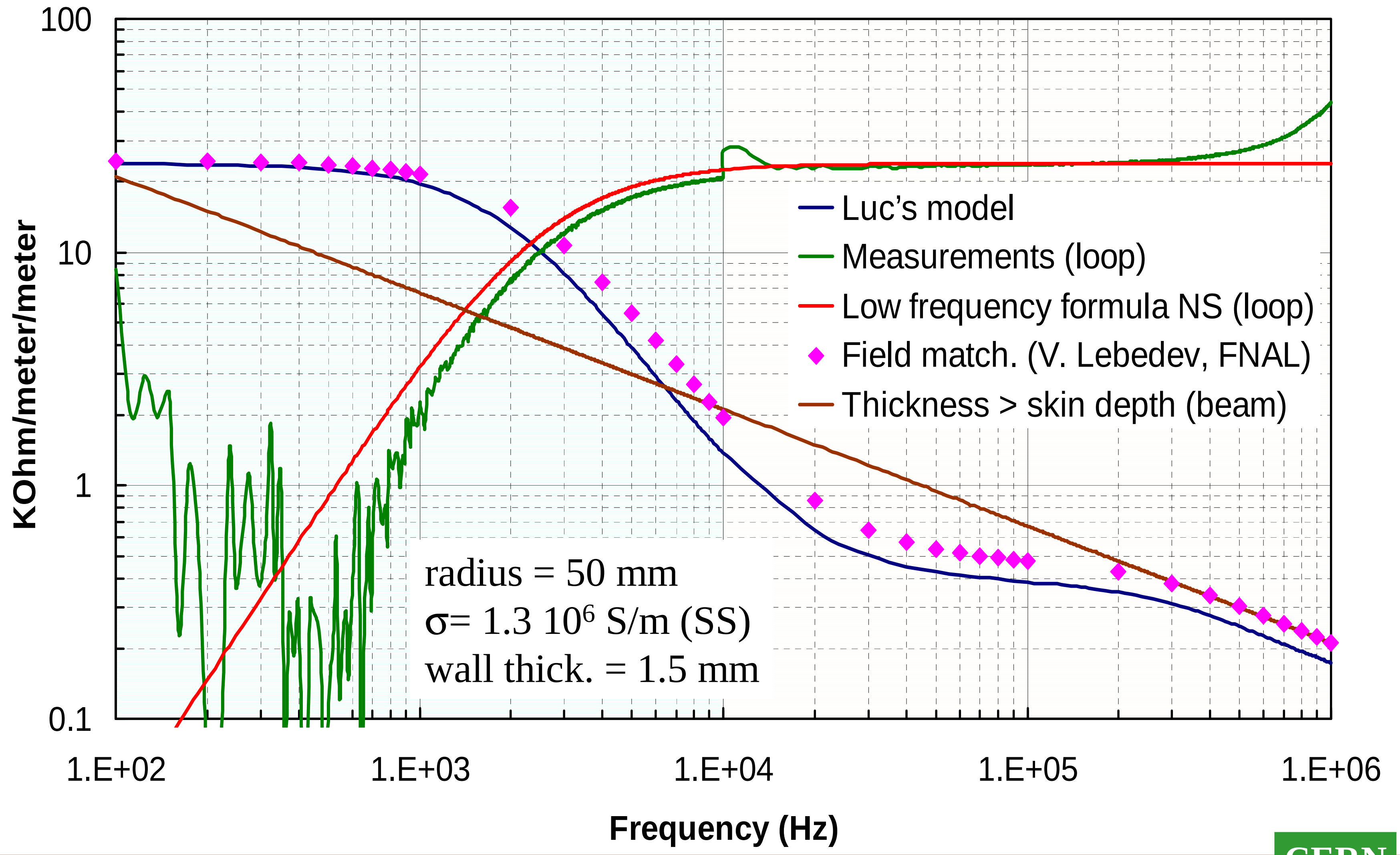
Im {trans. imp. per unit length}: circular pipe



radius = 50 mm

σ= 1.3 10^6 S/m (SS)

wall thick. = 1.5 mm

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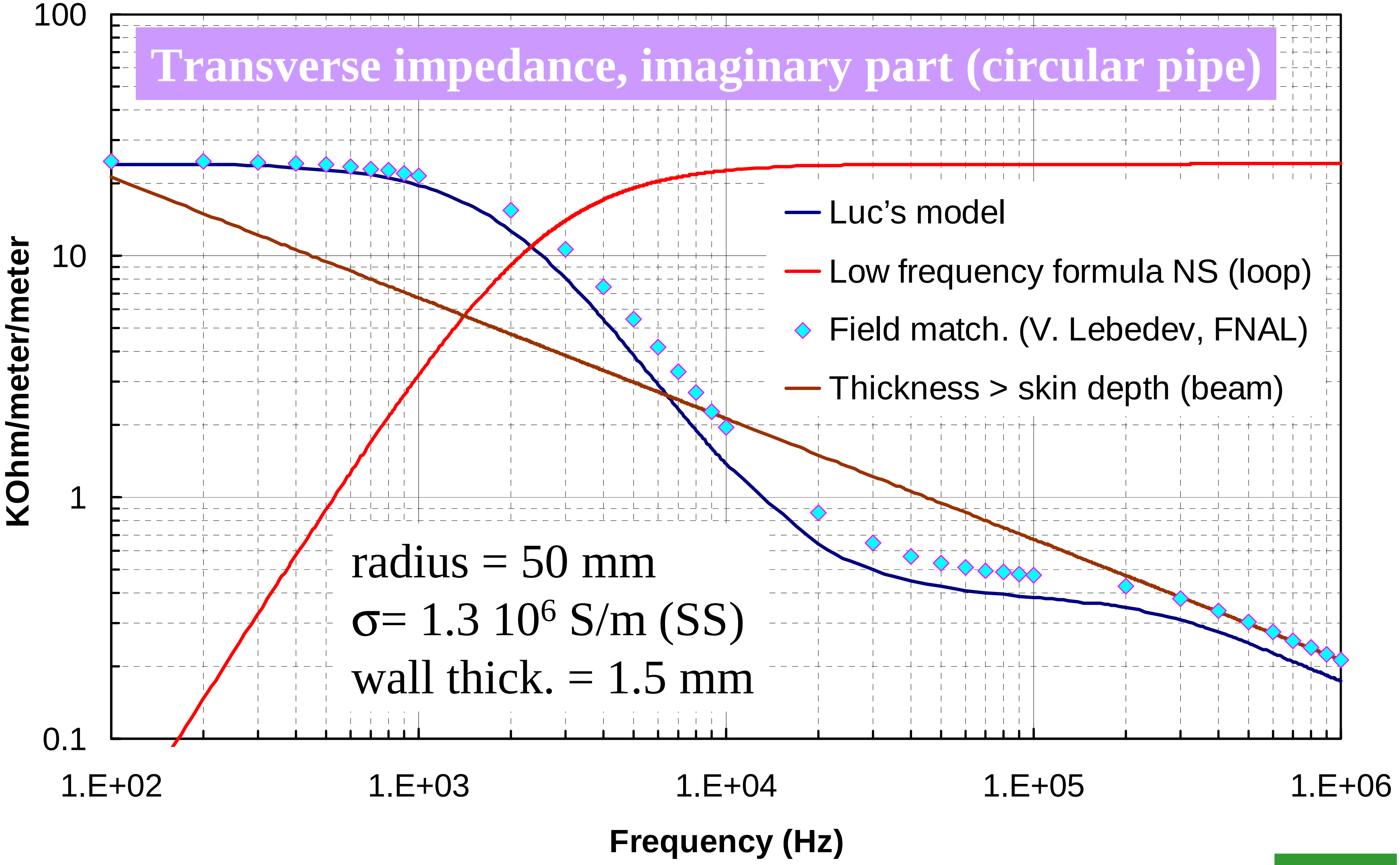
From theory …



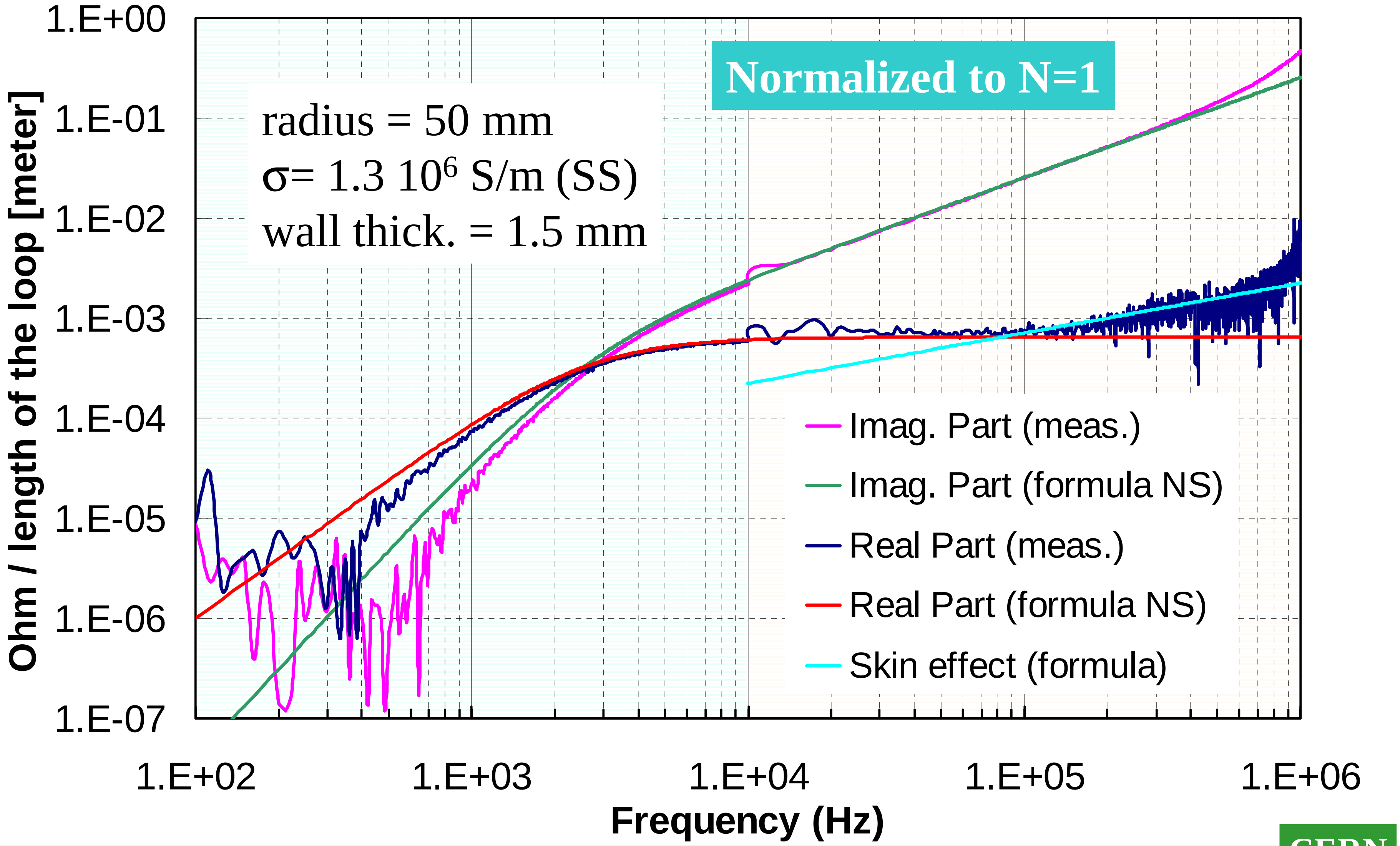
Transverse impedance, imaginary part (circular pipe)

radius = 50 mm

σ= 1.3 10^6 S/m (SS)

wall thick. = 1.5 mm

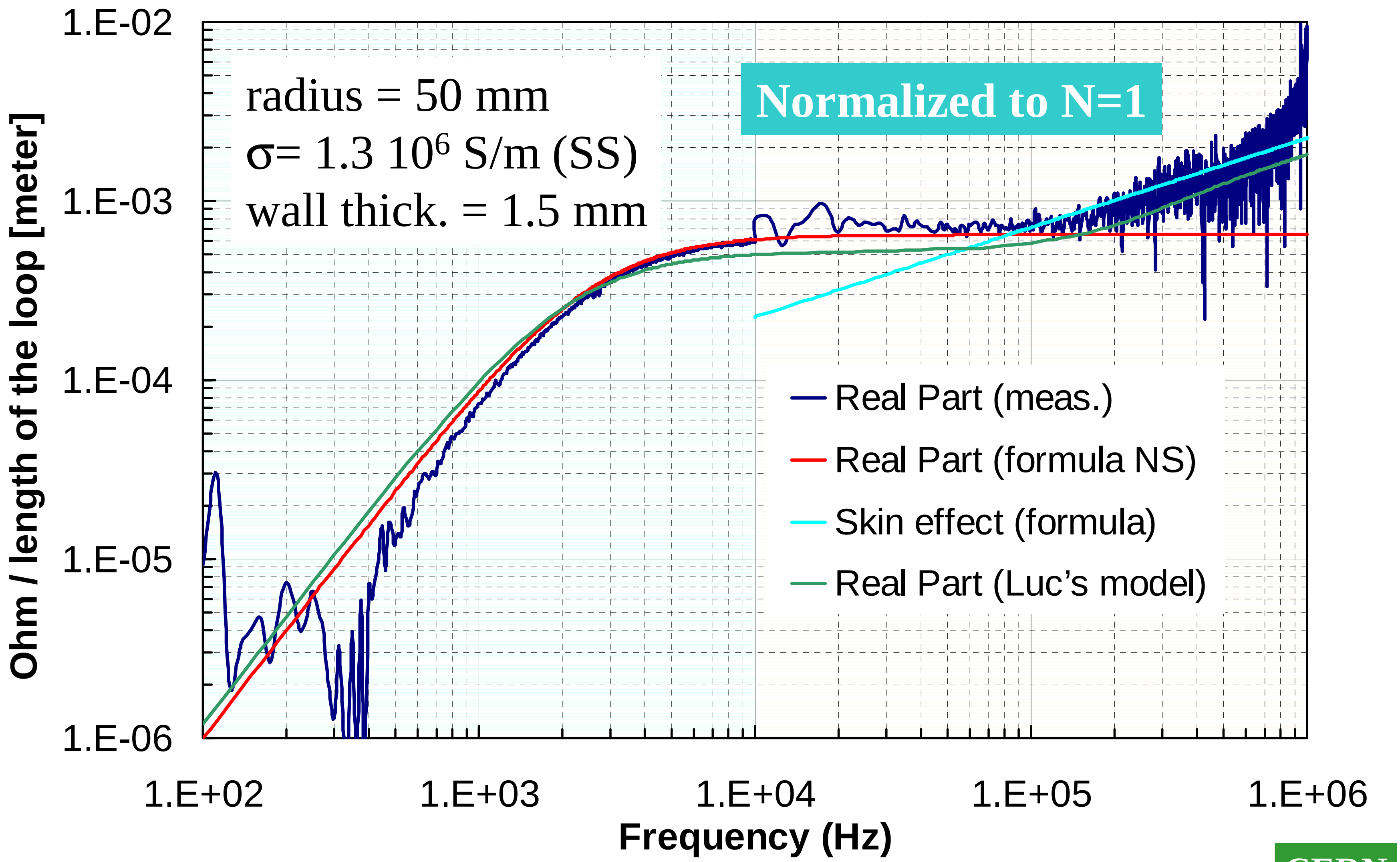
Added loop impedance: circular pipe



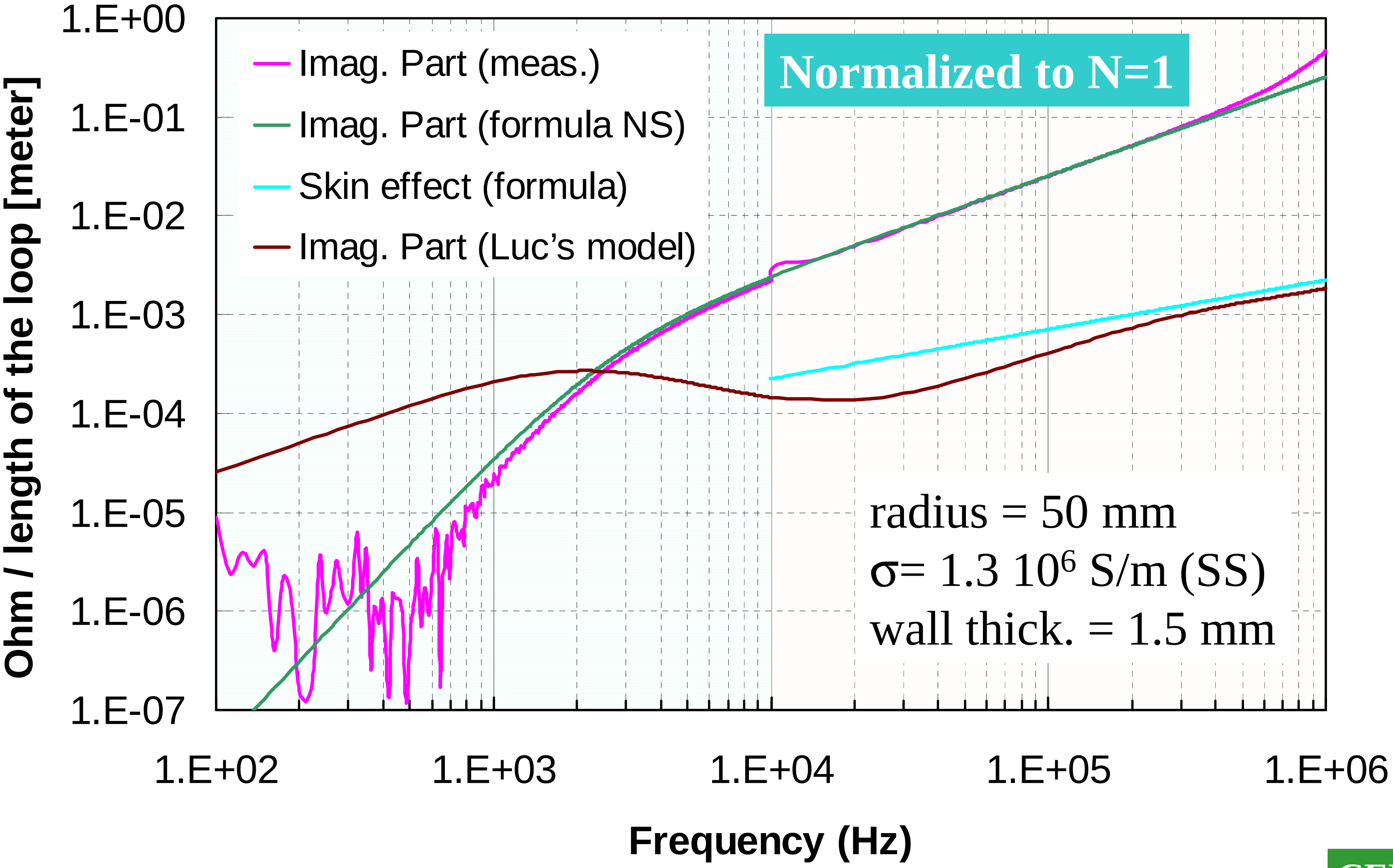
radius = 50 mm
σ= 1.3 10^6 S/m (SS)
wall thick. = 1.5 mm

Normalized to N=1

Added loop impedance: circular pipe



Added loop impedance: circular pipe



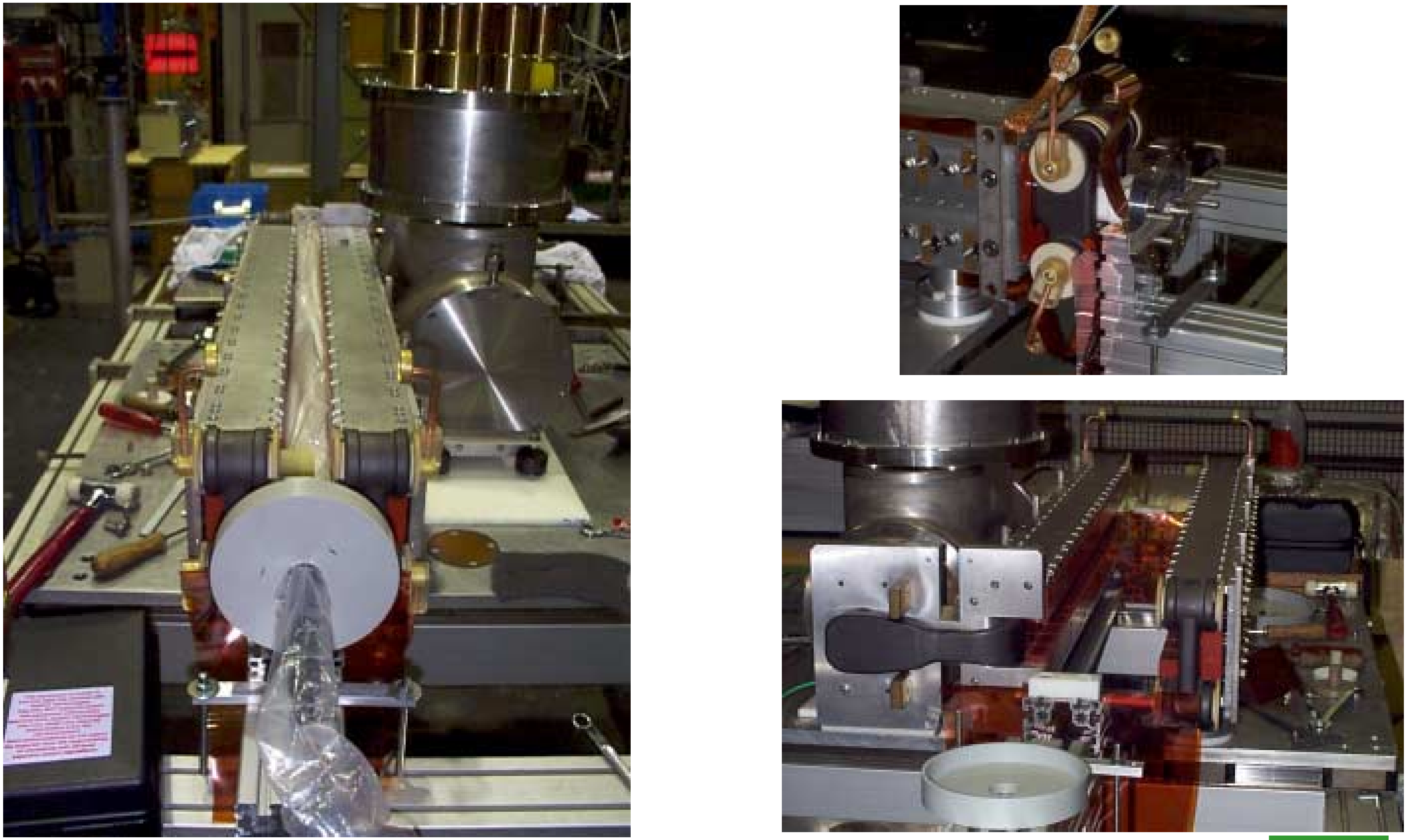
Normalized to N=1

radius = 50 mm
σ= 1.3 10^6 S/m (SS)
wall thick. = 1.5 mm

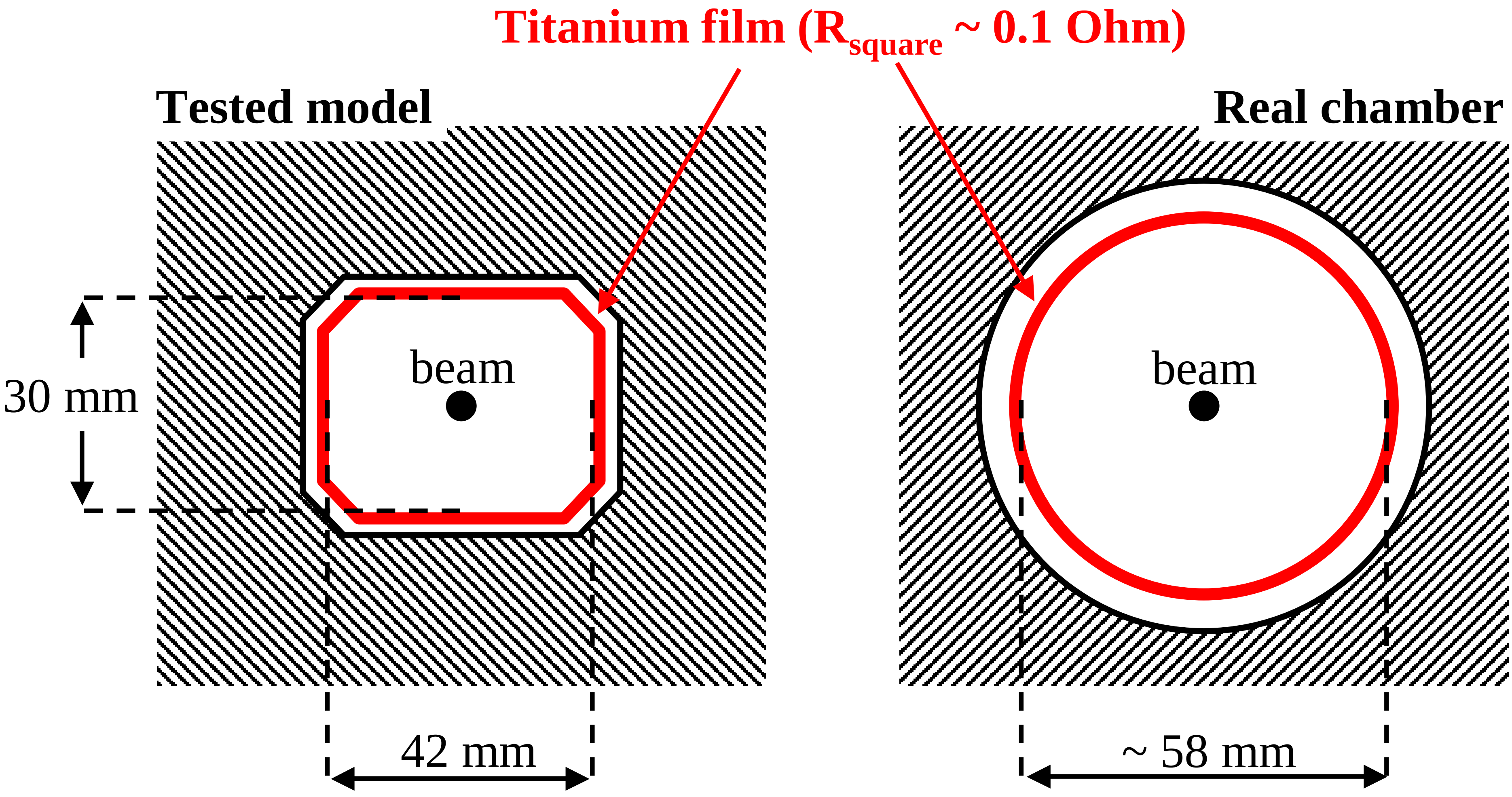
The reference measurement surprise

- At low frequencies the imaginary part **CAN NOT** be deduced from loop measurements. (hints of possible explanation from international discussion group).
- Good agreement measurement/theory of the real part (Nassibian Sacherer algorithm, both for added loop impedance and its conversion to transverse coupling impedance).
- The resonance frequency of the loop in the free space is about 1.5 MHz.

Kicker model under test



Kicker model under test: ceramic chamber



Titanium film (R_{square} ~ 0.1 Ohm)

Tested model

Real chamber

Longitudinal impedance from meas. data (I)

The length of the DUT is much smaller than the wavelength.

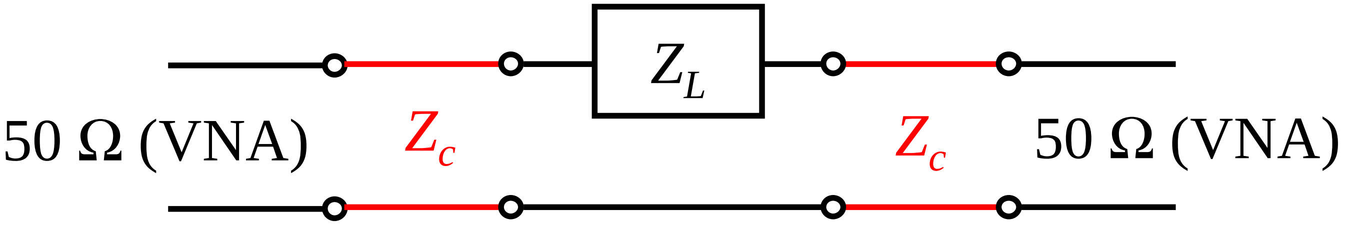
Transmission measurements

$$Z_L = 2Z_c\,\frac{1 - S_{12}}{S_{12}}$$

Reflection measurements

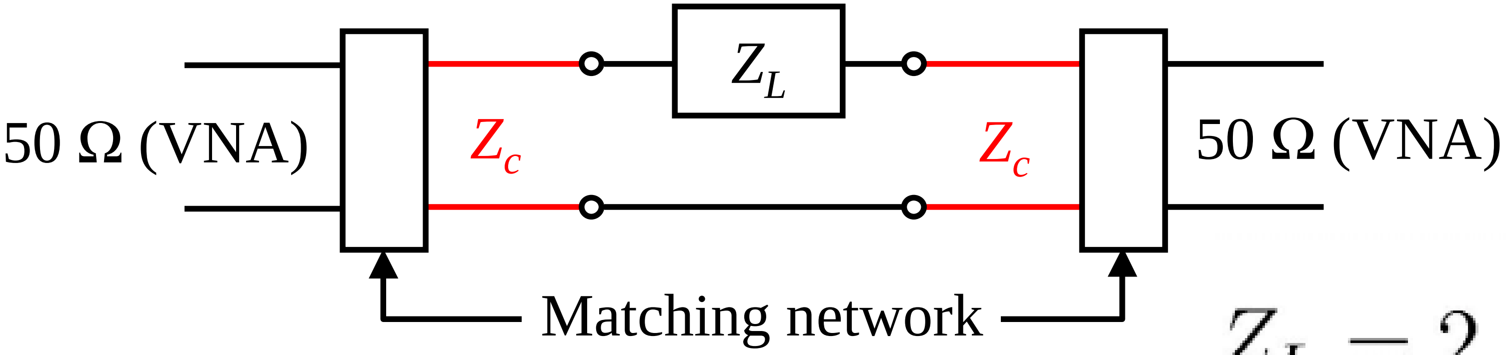
$$Z_L = Z_c\,\frac{1 + S_{11}}{1 - S_{11}}$$

Longitudinal impedance from meas. data (II)



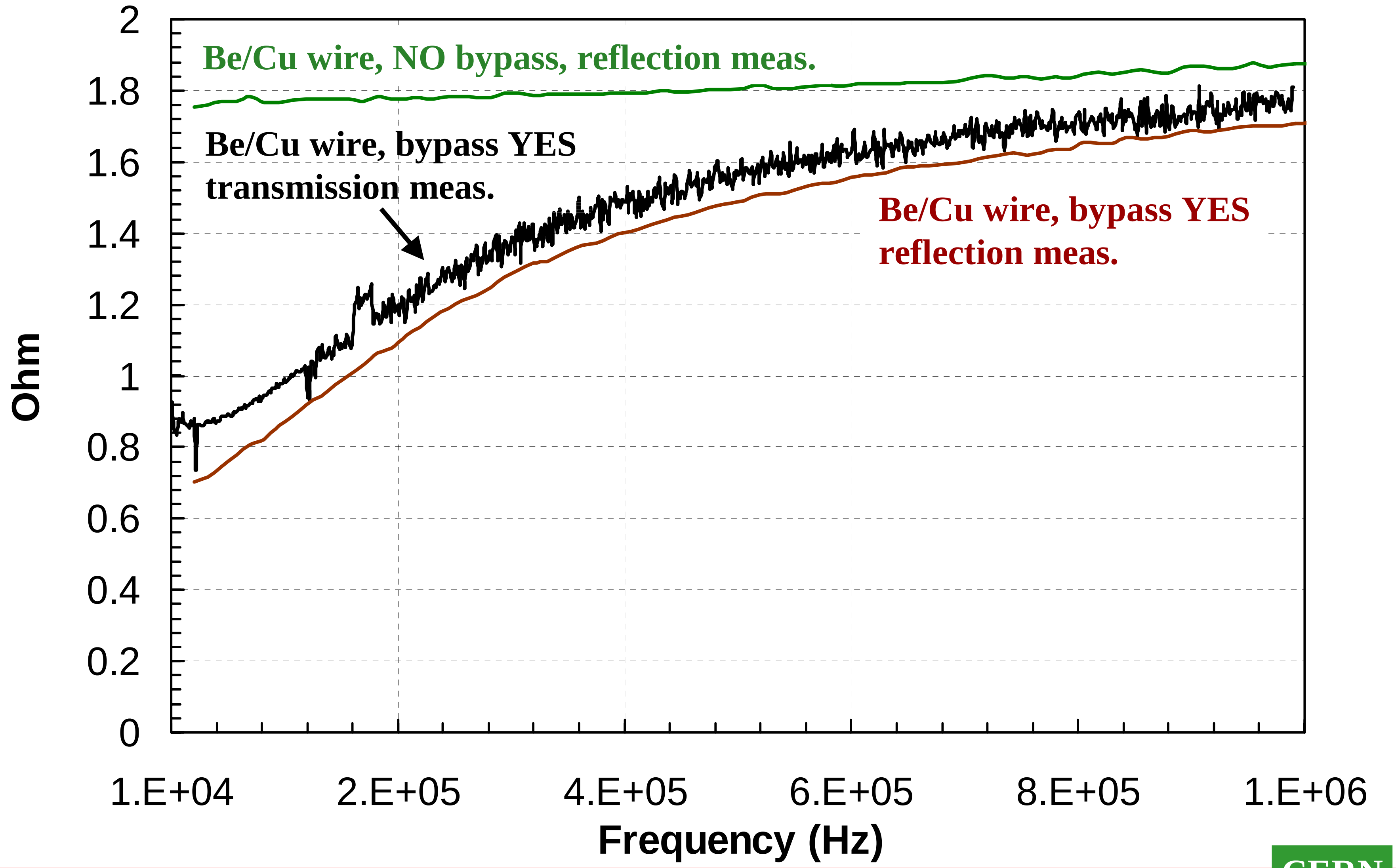
If Z_L is a lumped element and neglecting the two **very short** lines with Z_c (no matching network)

$$Z_L = 2\ Z_{50}\ \frac{1 - S_{12}^{50}}{S_{12}^{50}}$$

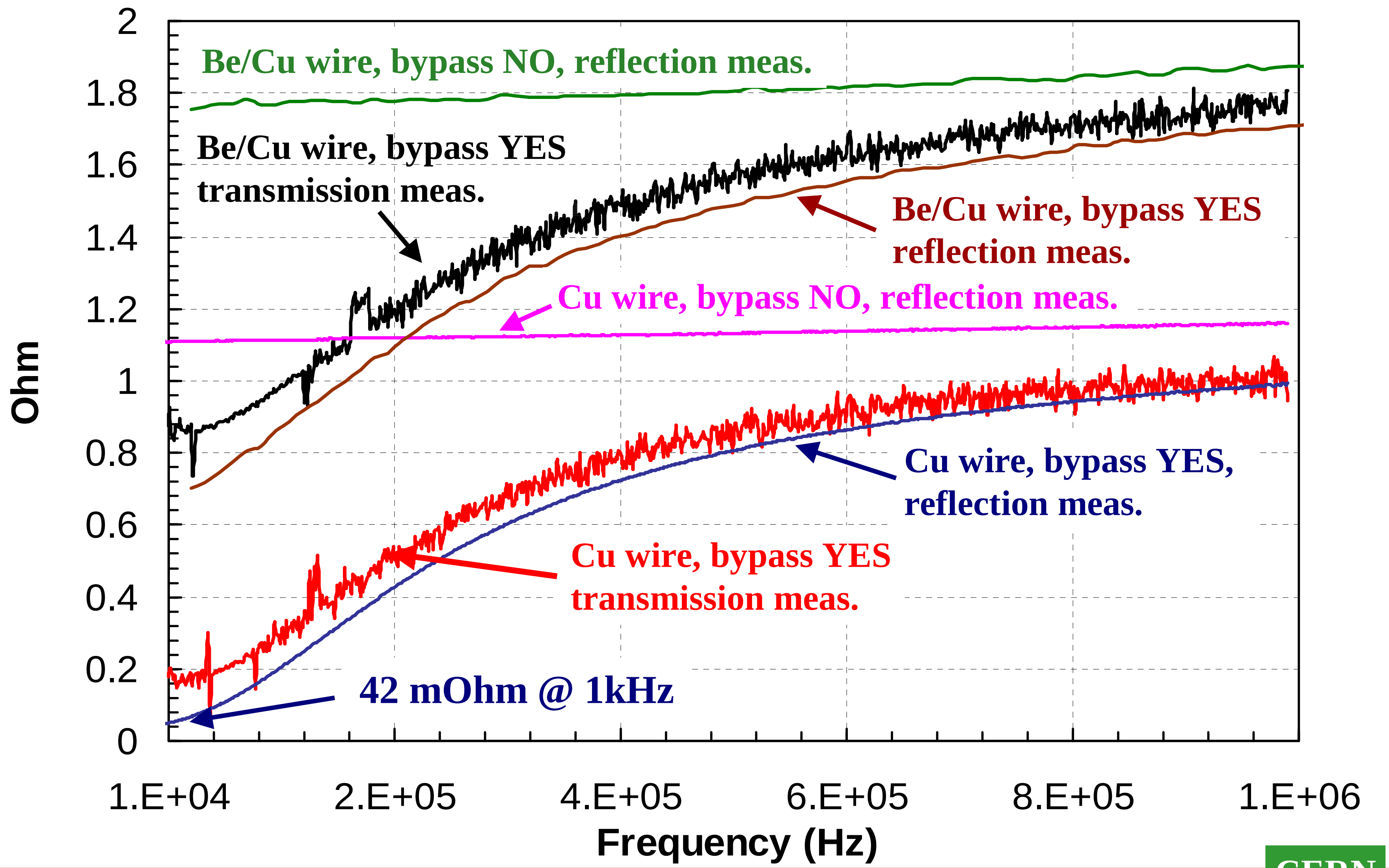


$$Z_L = 2\ Z_c\ \frac{1 - S_{12}^{50}}{S_{12}^{50}}$$

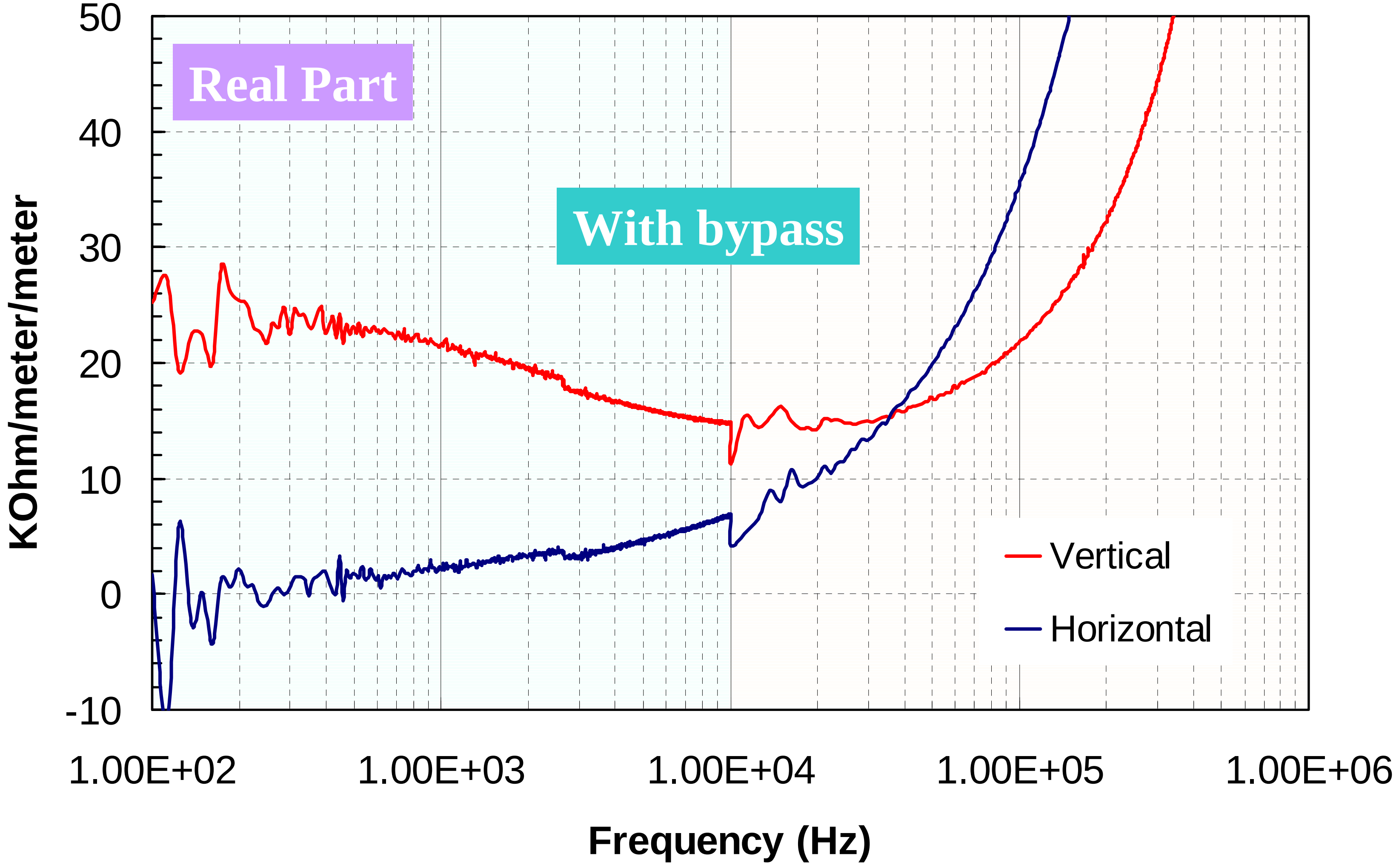
Longitudinal impedance (real part)



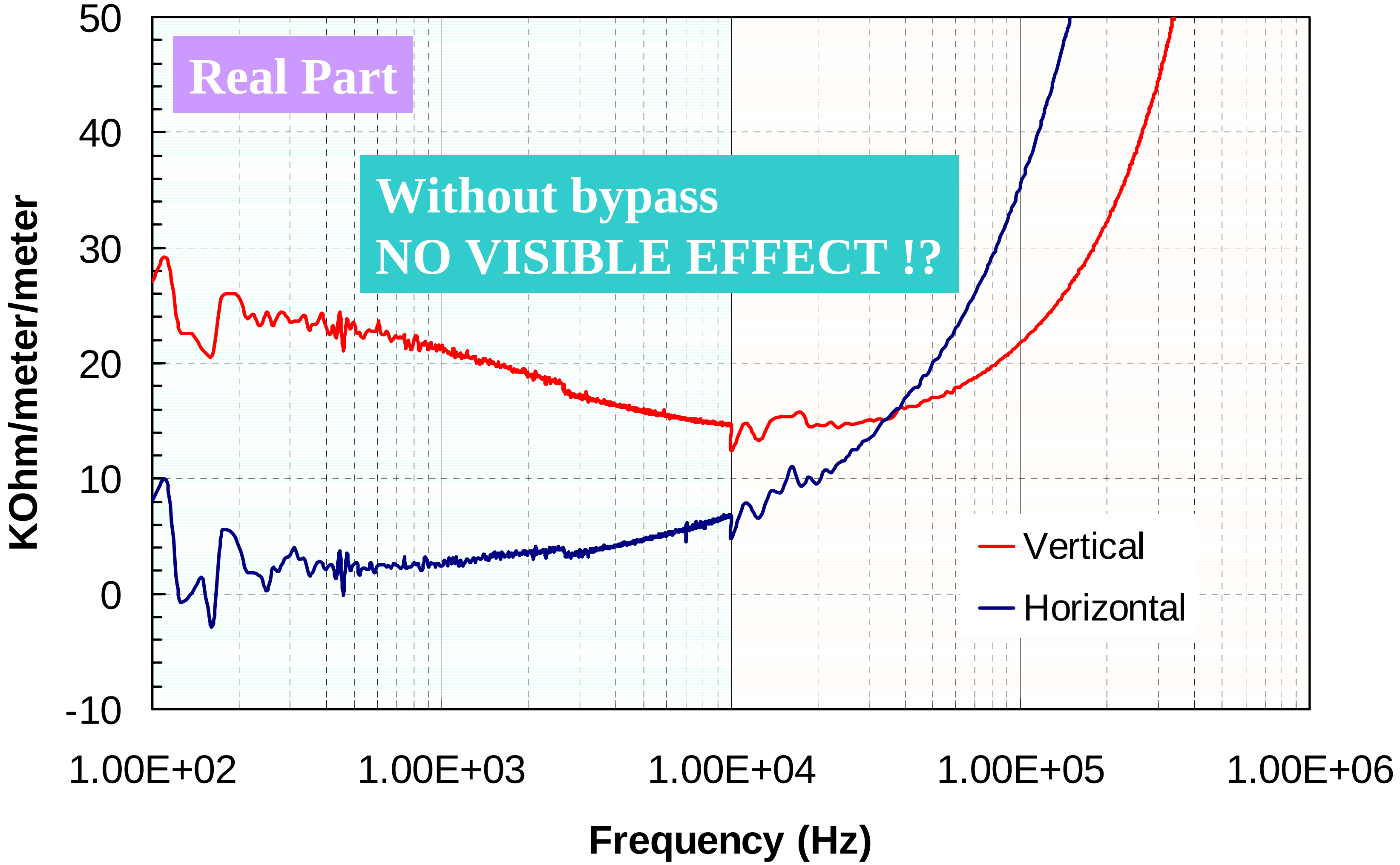
Longitudinal impedance (real part)



Trans. imp. per unit length: coil measurement



Trans. imp. per unit length: coil measurement



Real Part

Without bypass
NO VISIBLE EFFECT !?

Trans. imp. from displaced wire meas.

According to Nassibian Sacherer:

IF $Z_L = const + F^2(x_0)$ ⇒ $Z_T = \frac{c}{\omega}\left(\frac{dF}{dx_0}\right)^2$

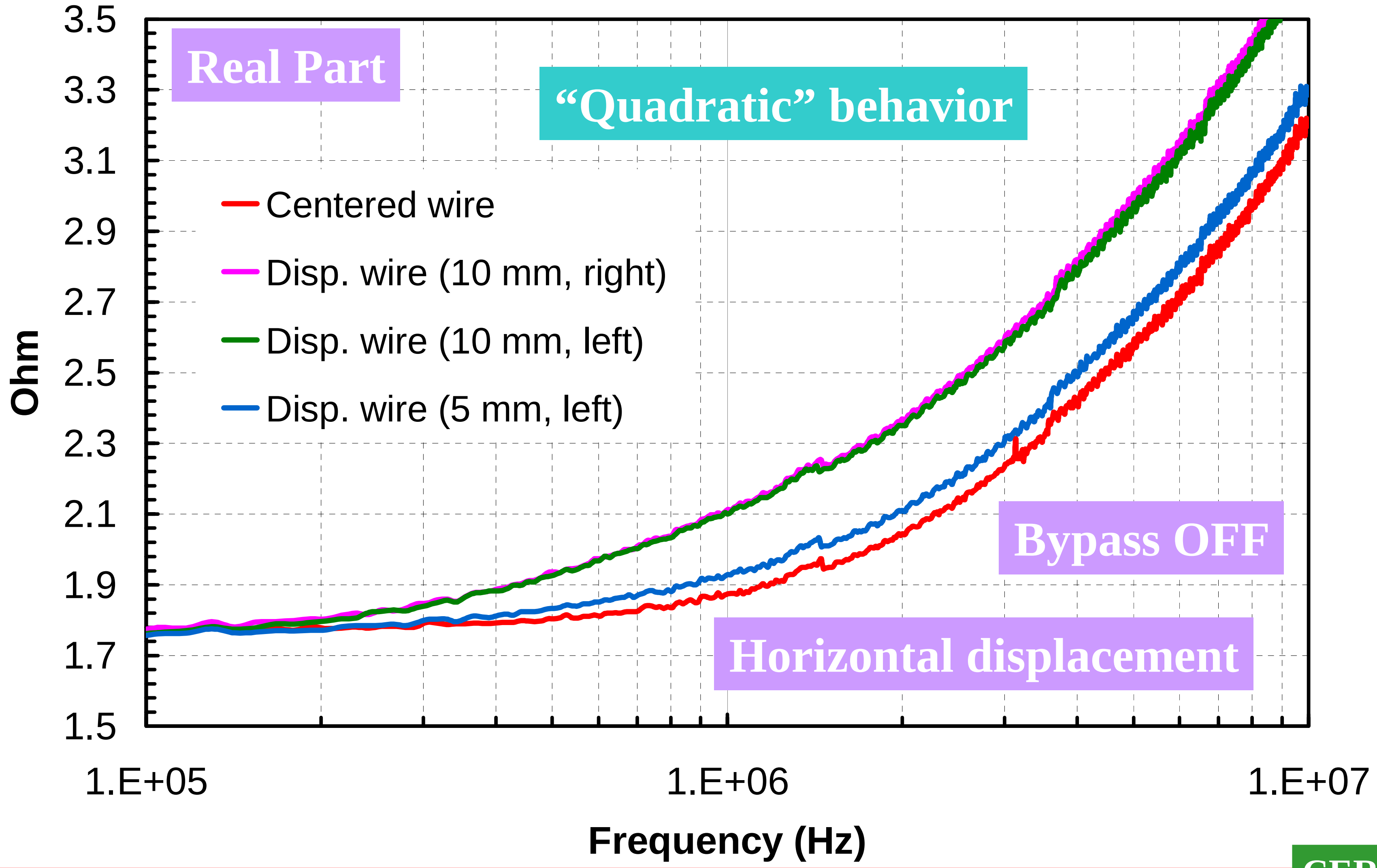
Since $Z_L(x_0) = Z_L(-x_0)$ ⇒ $Z_L(x_0) = Z_L(x_0 = 0) + a^2 x_0^2 + \ldots$

Then, assuming $F(x_0) \approx a\, x_0$

⇒ $$Z_T = \frac{c}{\omega}\,\frac{Z_L(x_0) - Z_L(x_0 = 0)}{x_0^2}$$

← measured displacing the wire of x_0.

Long. imp. vs wire displacement



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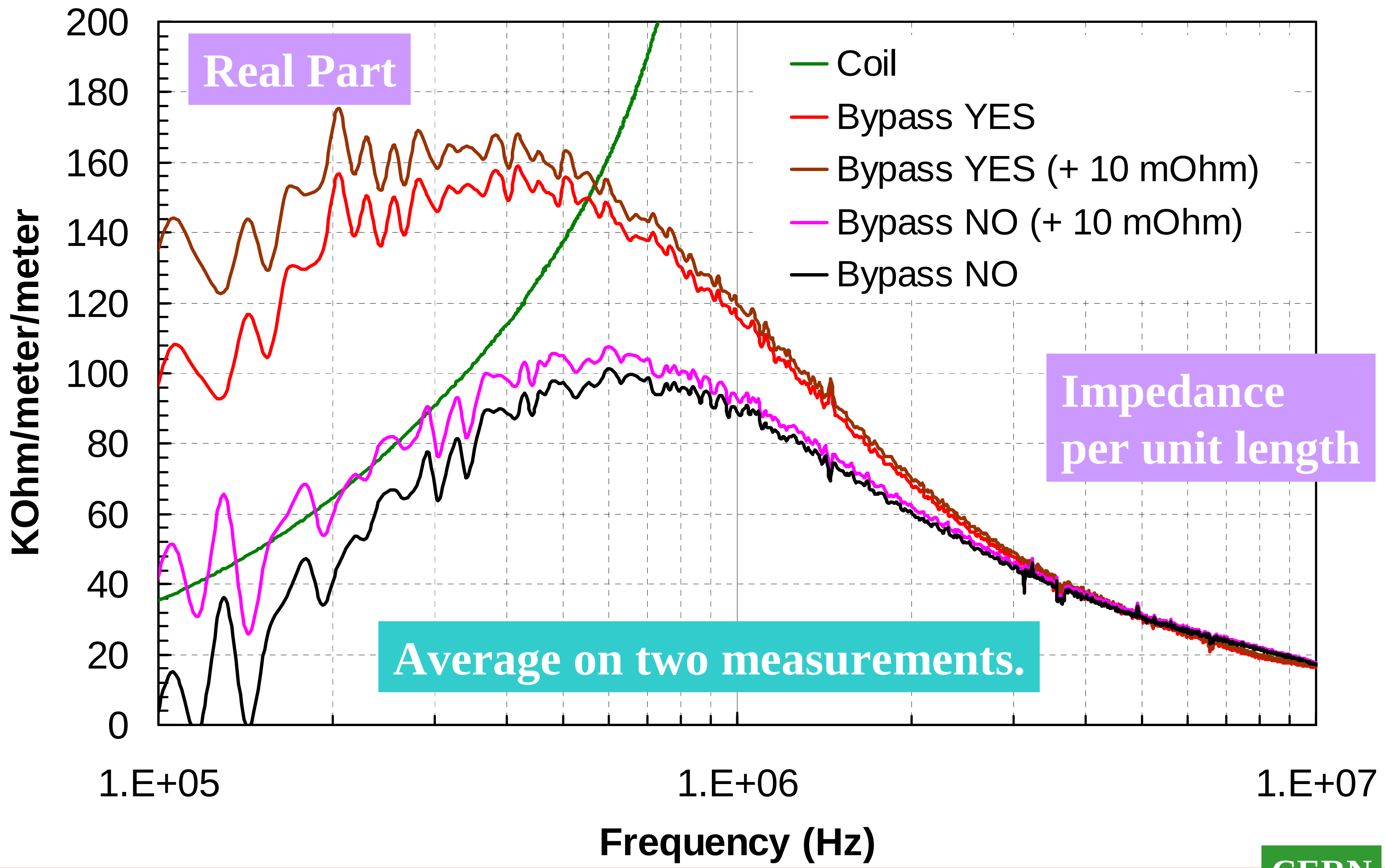
Horizontal transverse imp.: displaced wire



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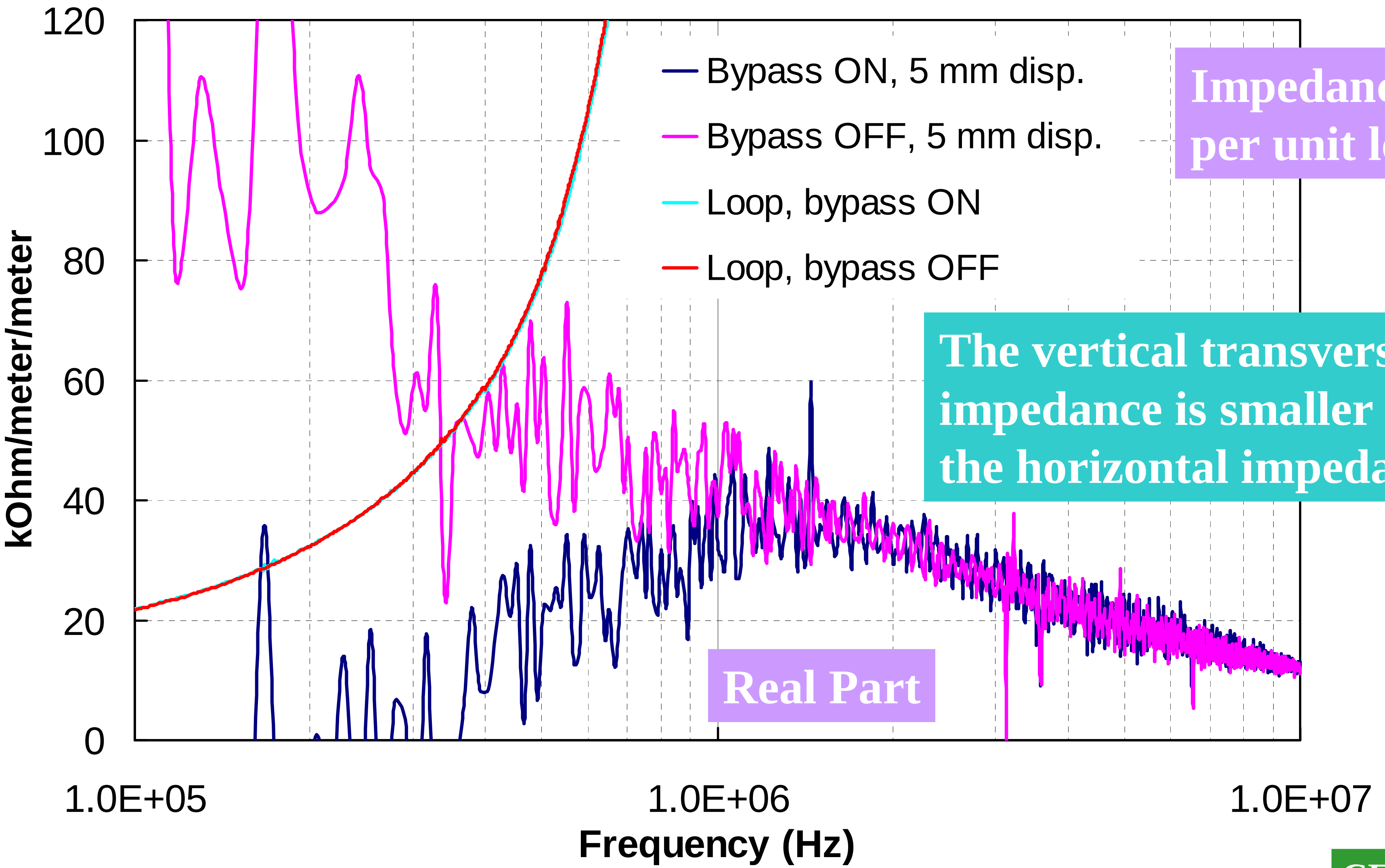
Vertical transverse imp. : displaced wire



Impedance per unit length

The vertical transverse impedance is smaller than the horizontal impedance.

Real Part

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Conclusion (I)

- Clear effect of the bypass on the longitudinal impedance.
- No effect of the bypass on the coil measurement (transverse impedance).
- Clear effect of the bypass on the offset wire measurement (transverse impedance).

Conclusion (II)

- The presently available model is pessimistic by a factor 3÷5 with respect to the final version (different ceramic chambers). The loop was designed for a model (with diameter 60 mm) and it is too big for the actual model.
- At frequencies > 0.5 MHz, the resistive horizontal impedance > than the vertical one (from displaced wire and loop meas.), contrary to what one would expect.
- From the available data, we estimate (scaling) the maximum of the transverse impedance (final dump kicker) is ~ 1 MOhm/m at 0.5 MHz and considerably less at ~ 10 kHz.

Bibliography

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