EM simulations in beam coupling impedance studies: some examples of application

C. Zannini and G. Rumolo

Thanks to: M. Barnes, F. Caspers, H. Day, G. De Michele, E. Métral, B. Salvant, V. G. Vaccaro

Overview

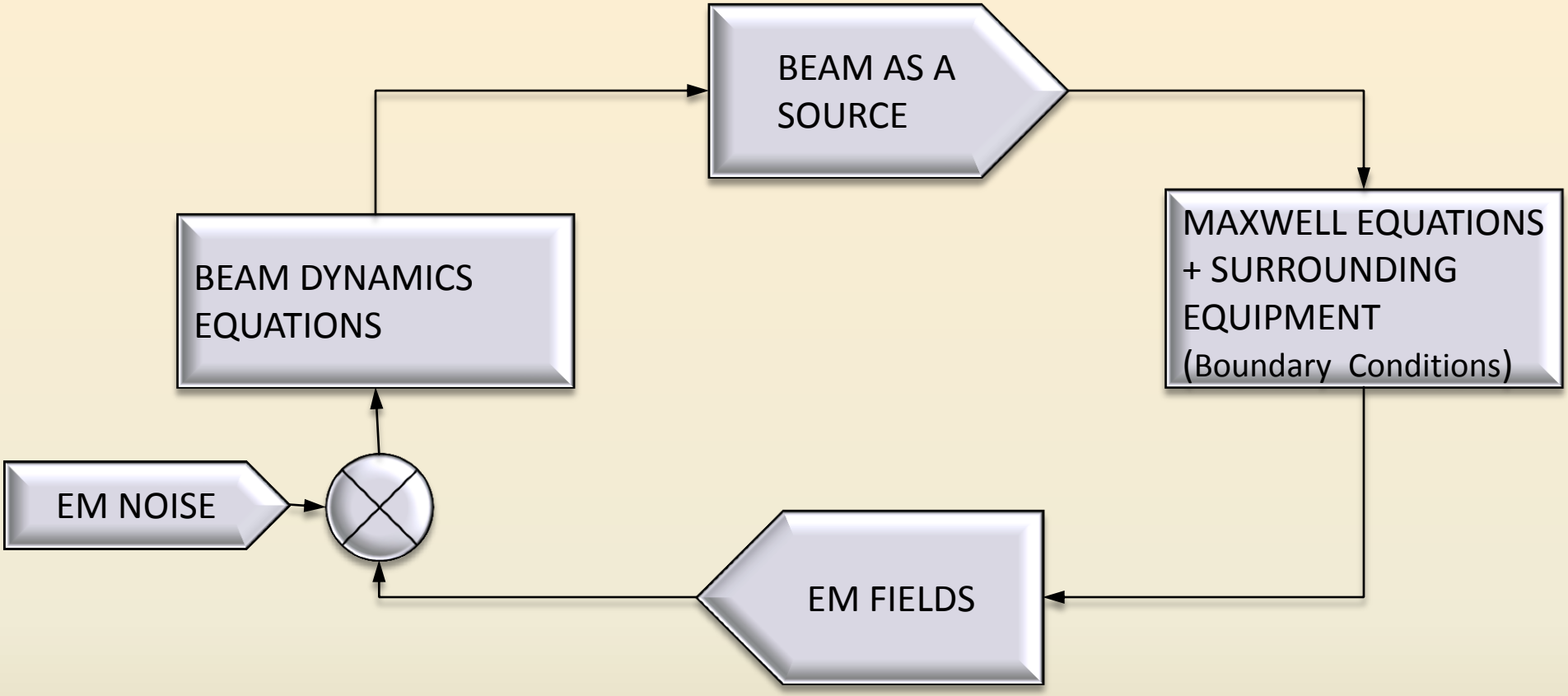
Introduction

SPS Kicker impedance model

- From simple to realistic models
- Experimental confirmations
- Numerical investigation of bench impedance measurements
- Ferrite model

Summary

Background



A small perturbation in the ideal configuration of the beam can become a source of EM fields which enhance the perturbation itself. This can produce an avalanche effect which destroys the beam.

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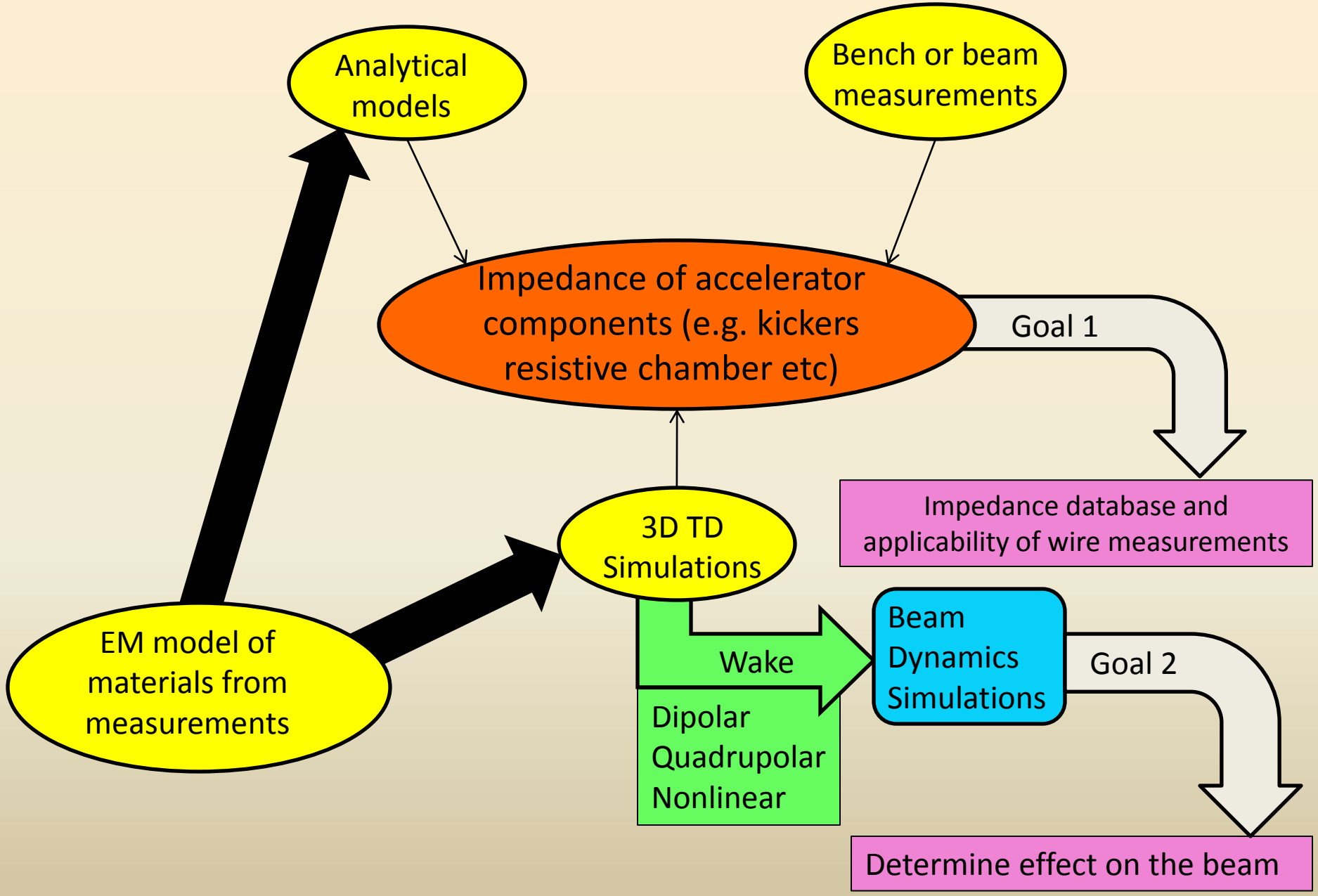

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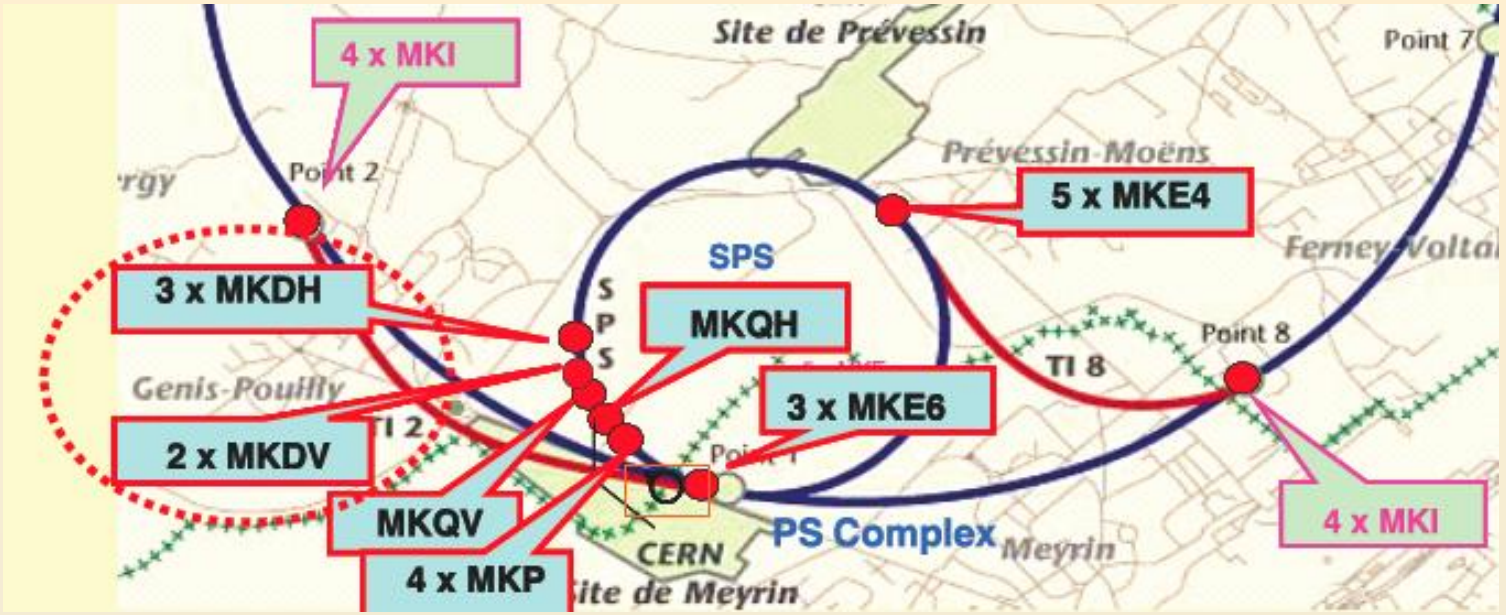

Courtesy M. Barnes

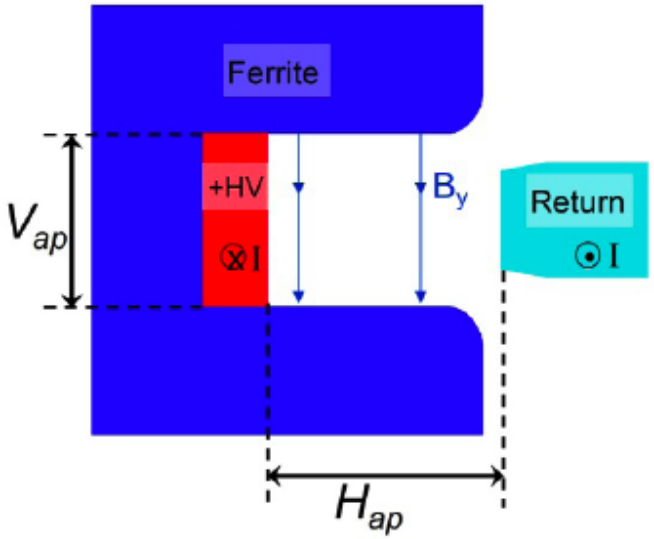

Figure 1: Simplified cross-section of a kicker magnet.

Table 1: SPS kicker system parameters

Kicker Magnet	Nb of magnets	H_{ap} (mm)	V_{ap} (mm)	Length x number of cells
MKP-S	12	100	61	26mm x 17
MKP-L	2	140	54	26mm x 22
MKQH	1	135	33.9	242mm x 2
MKQV	1	56	102	788mm x 2
MKDH1/2	2	97.1	56	1256mm x 1
MKDH3	1	106.1	60	1256mm x 1
MKDV1	1	56	75	512mm x 5
MKDV2	1	56	83	512mm x 5
MKE4-L	3	147.7	35	240mm x 7
MKE4-S	2	135	32	240mm x 7
MKE6-L	2	147.7	35	240mm x 7
MKE6-S	1	135	32	240mm x 7

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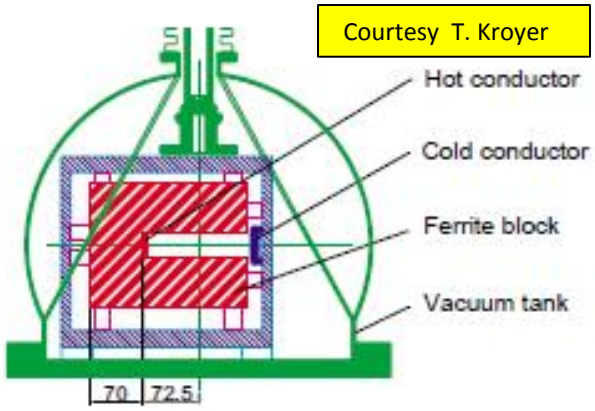
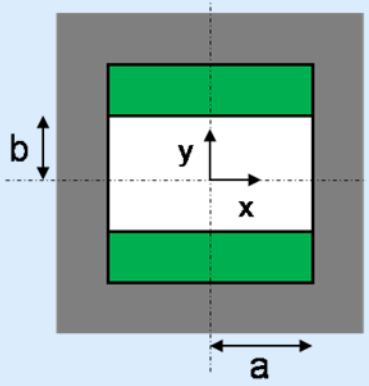
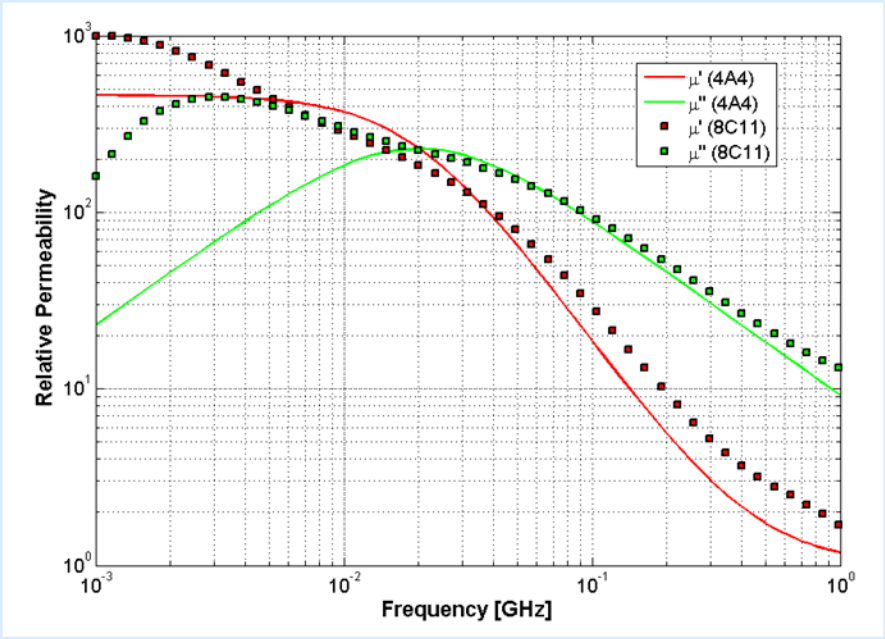
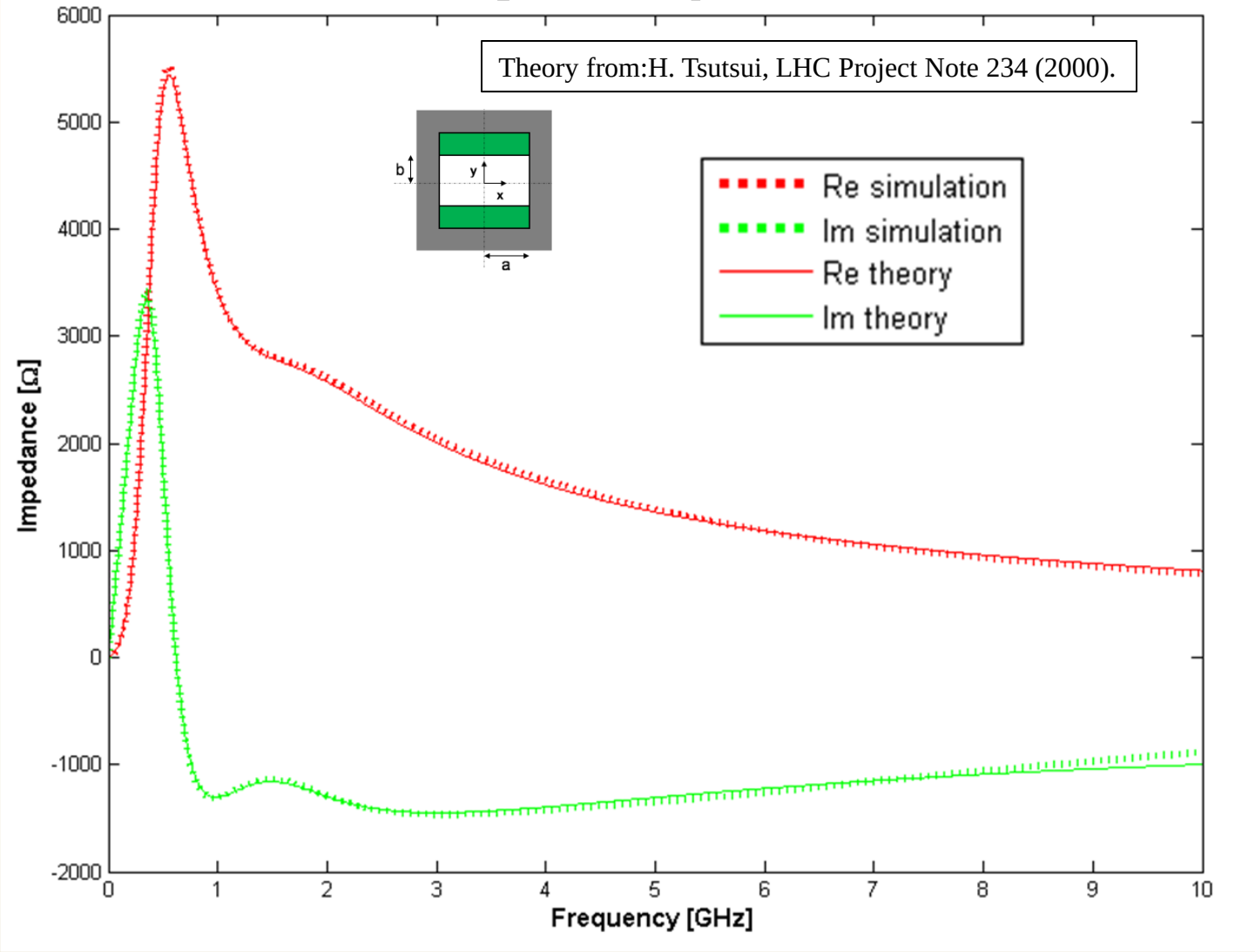
Simplified kicker model





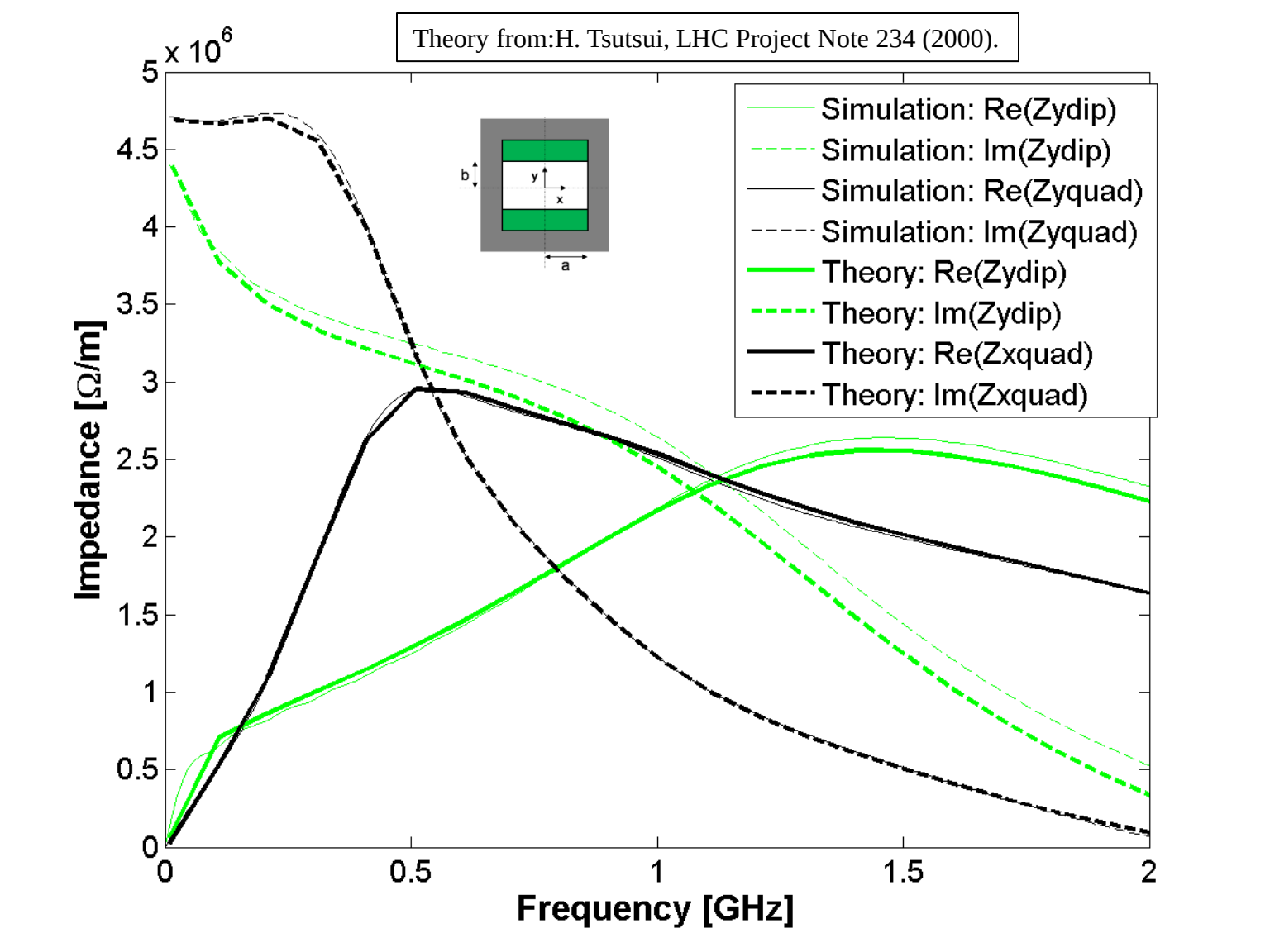


Longitudinal Impedance



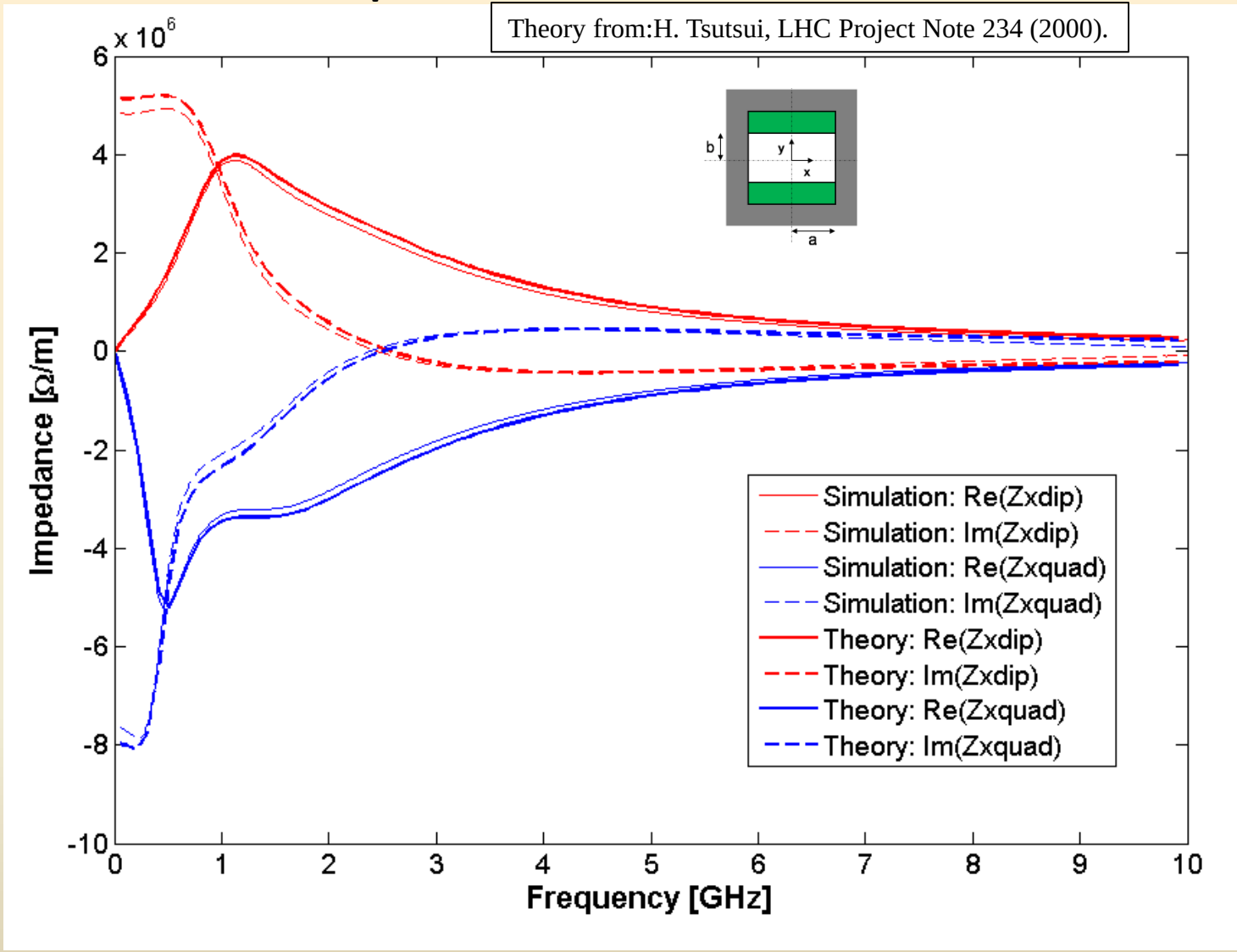
The theoretical predictions and simulations are in very good agreement

Vertical impedances for all the SPS kickers



The theoretical predictions and simulations are in very good agreement

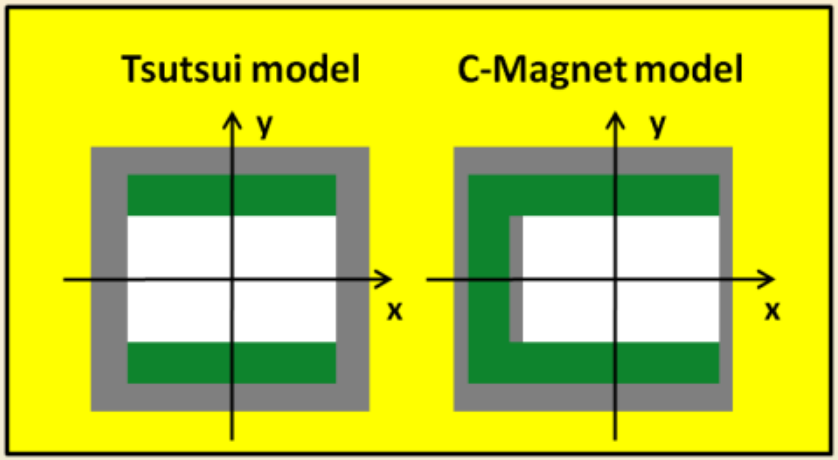
Horizontal impedance for all the SPS kickers



The theoretical predictions and simulations are in very good agreement

We are confident with the 3D TD EM simulation code (CST Particle Studio)

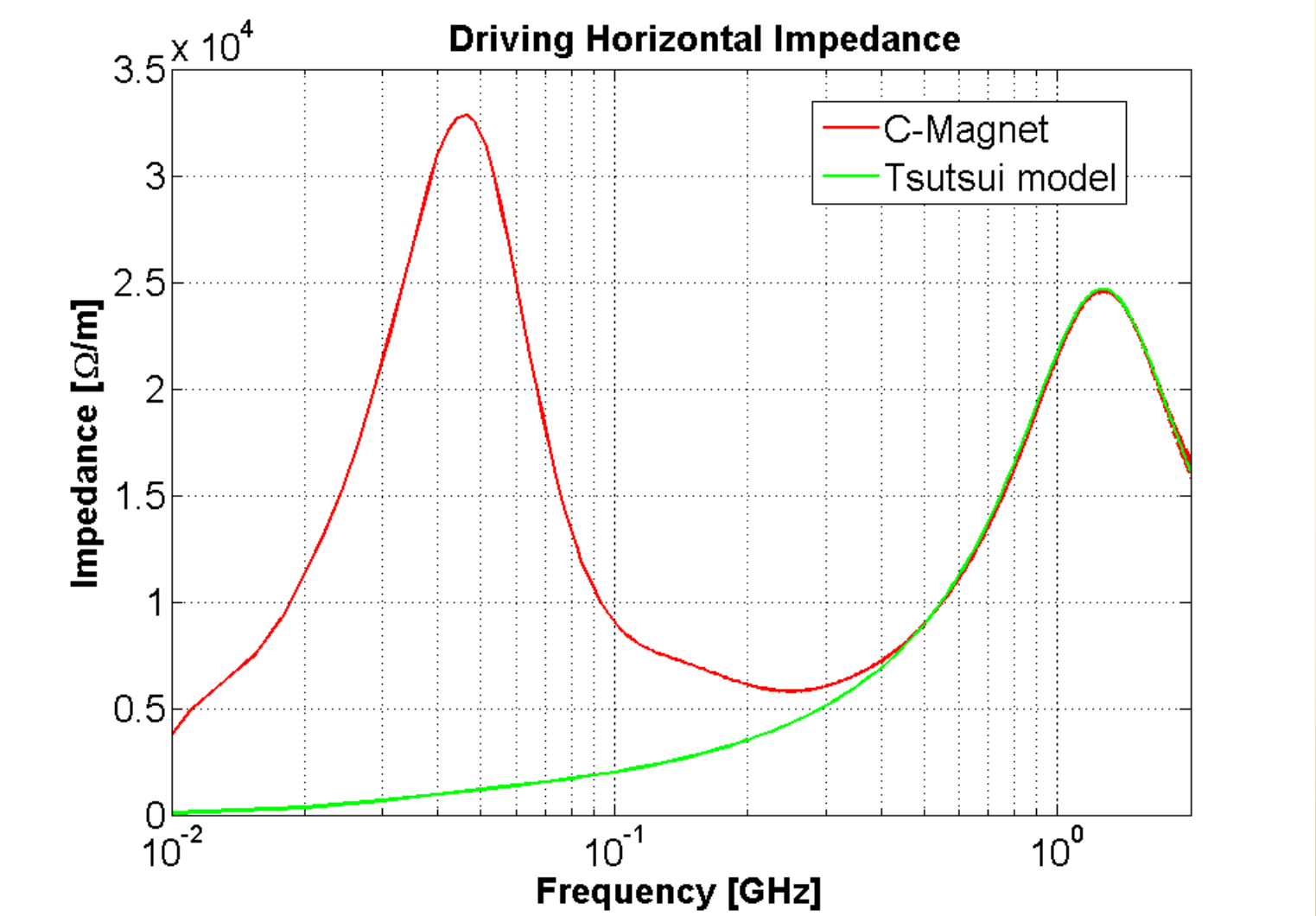
Improving the model



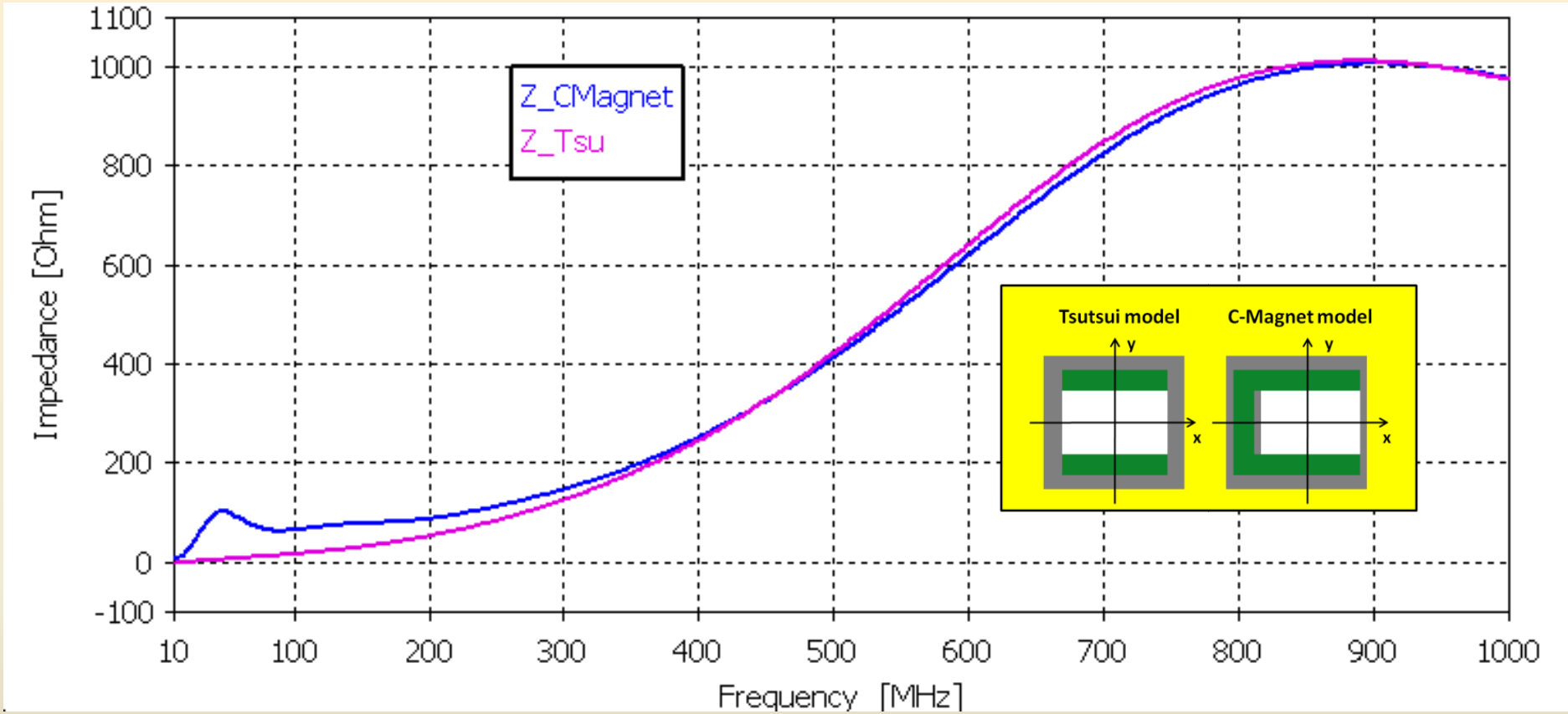
In the real structure there is a TEM propagation

The TEM mode plays a role when the penetration depth in the ferrite becomes comparable to the magnetic circuit length (below few hundred MHZ).

C-magnet: driving horizontal impedance

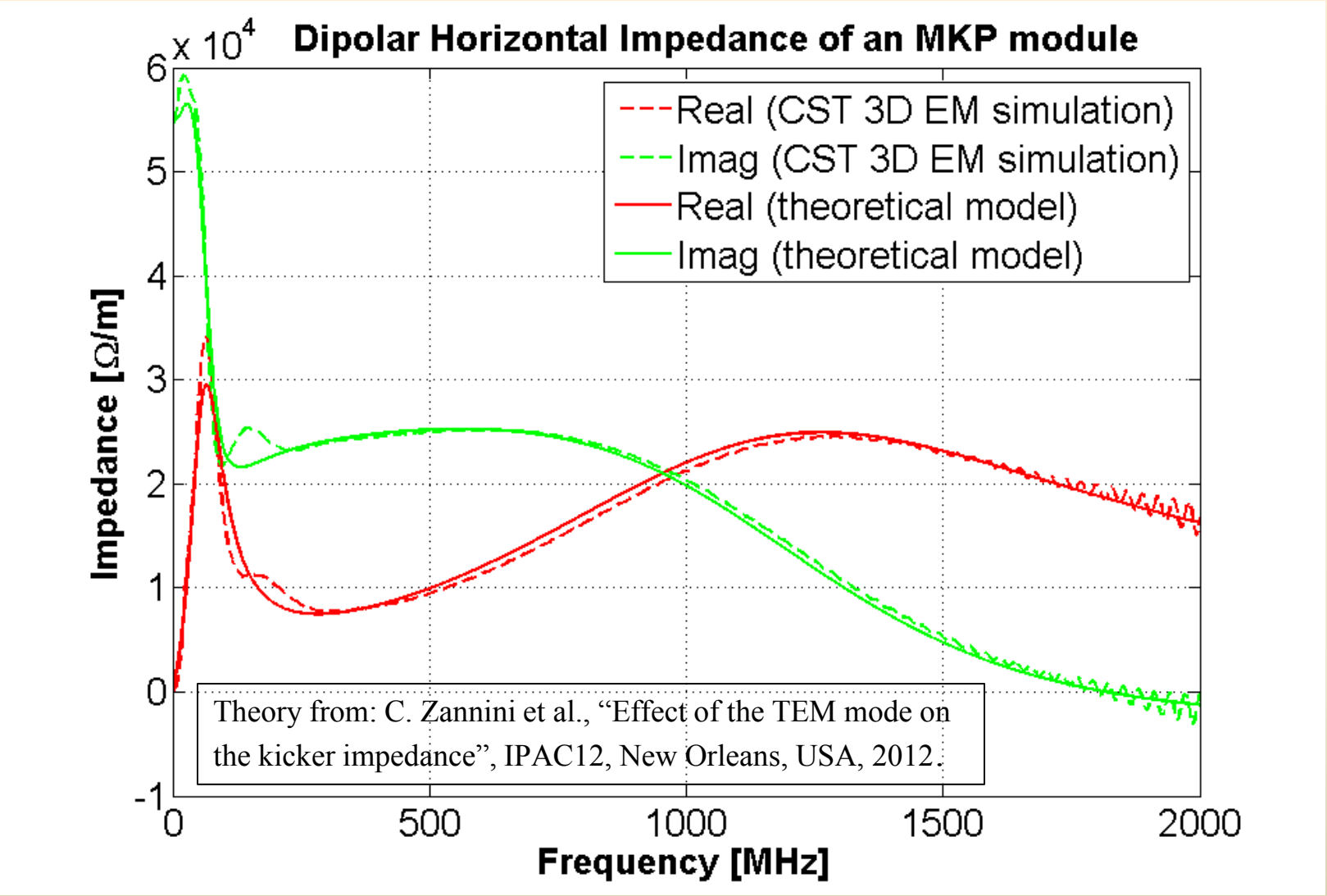


Comparing longitudinal impedance



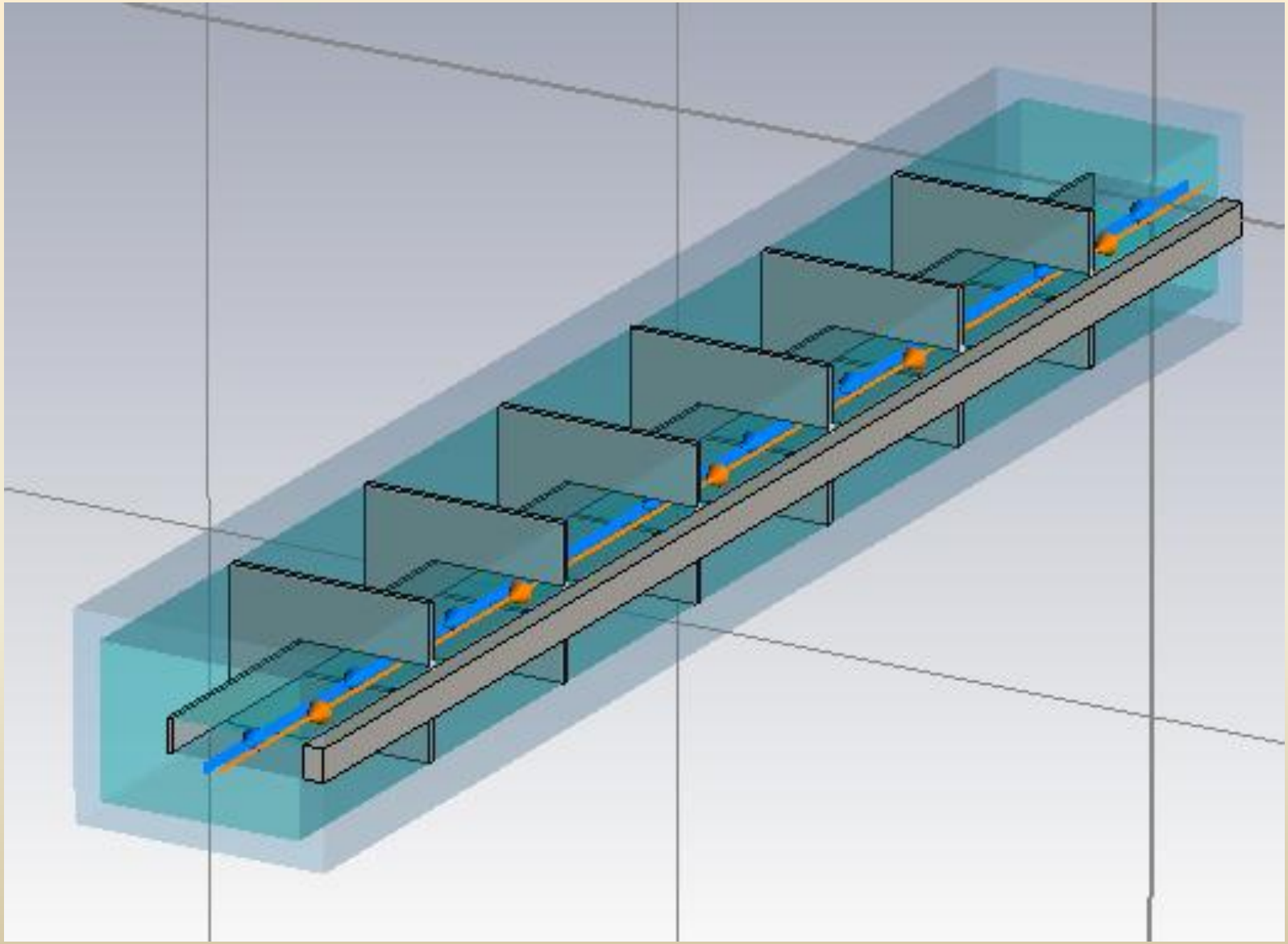
The peak appears also in the longitudinal impedance

C-Magnet: Comparing theoretical model and 3-D simulations

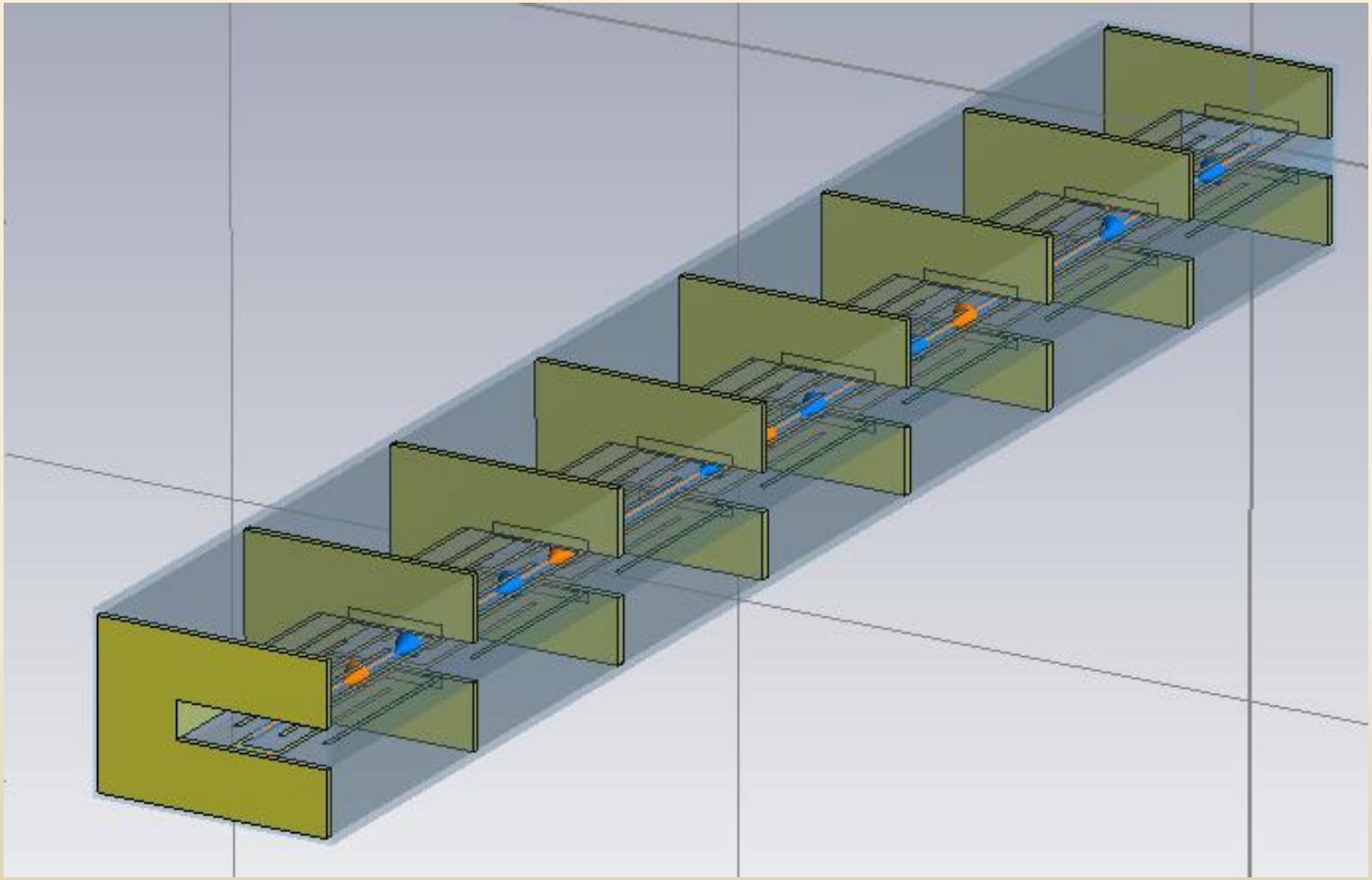


The theoretical predictions and simulations show a very good agreement

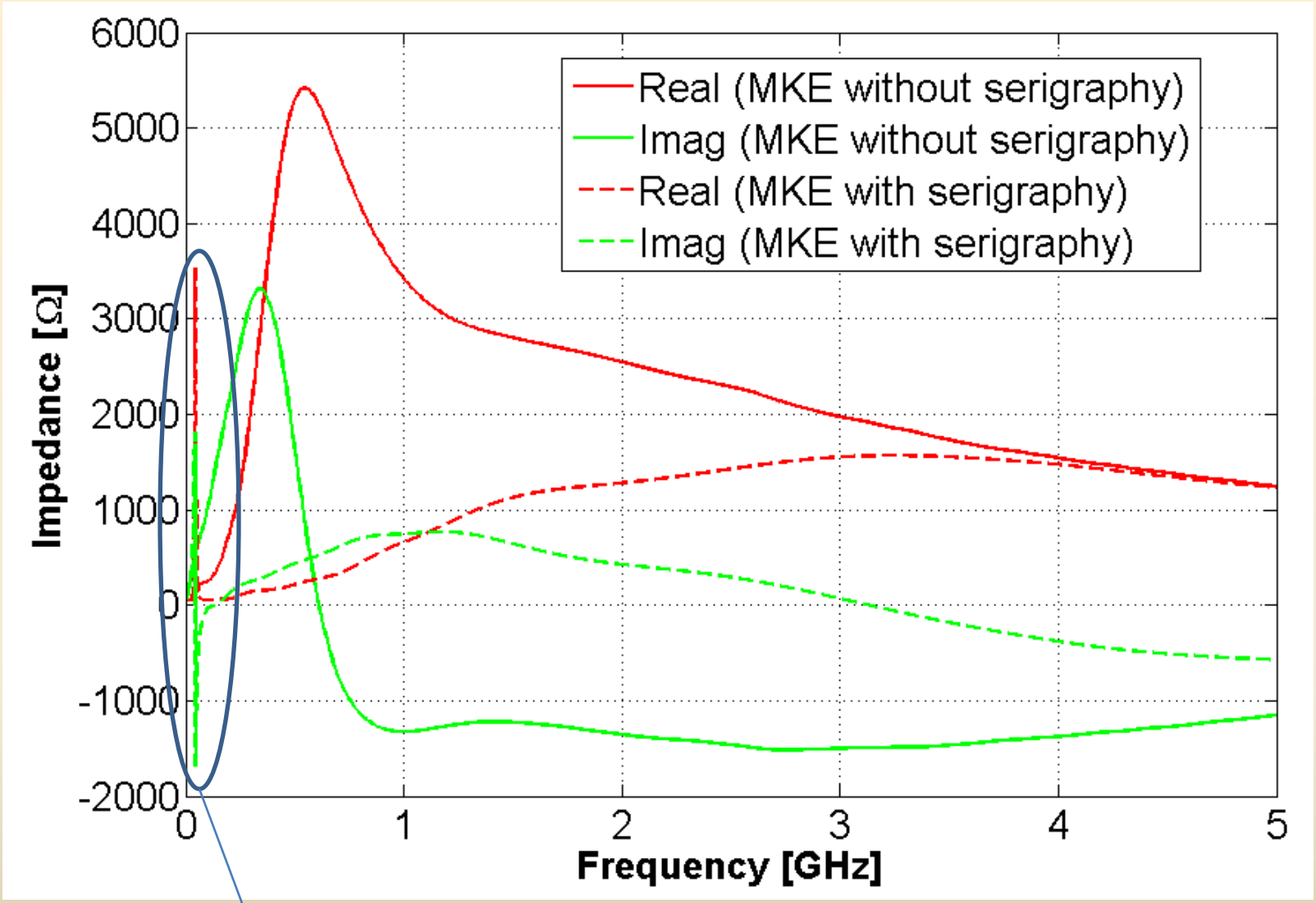
SPS extraction kicker (MKE)



MKE kicker with serigraphy



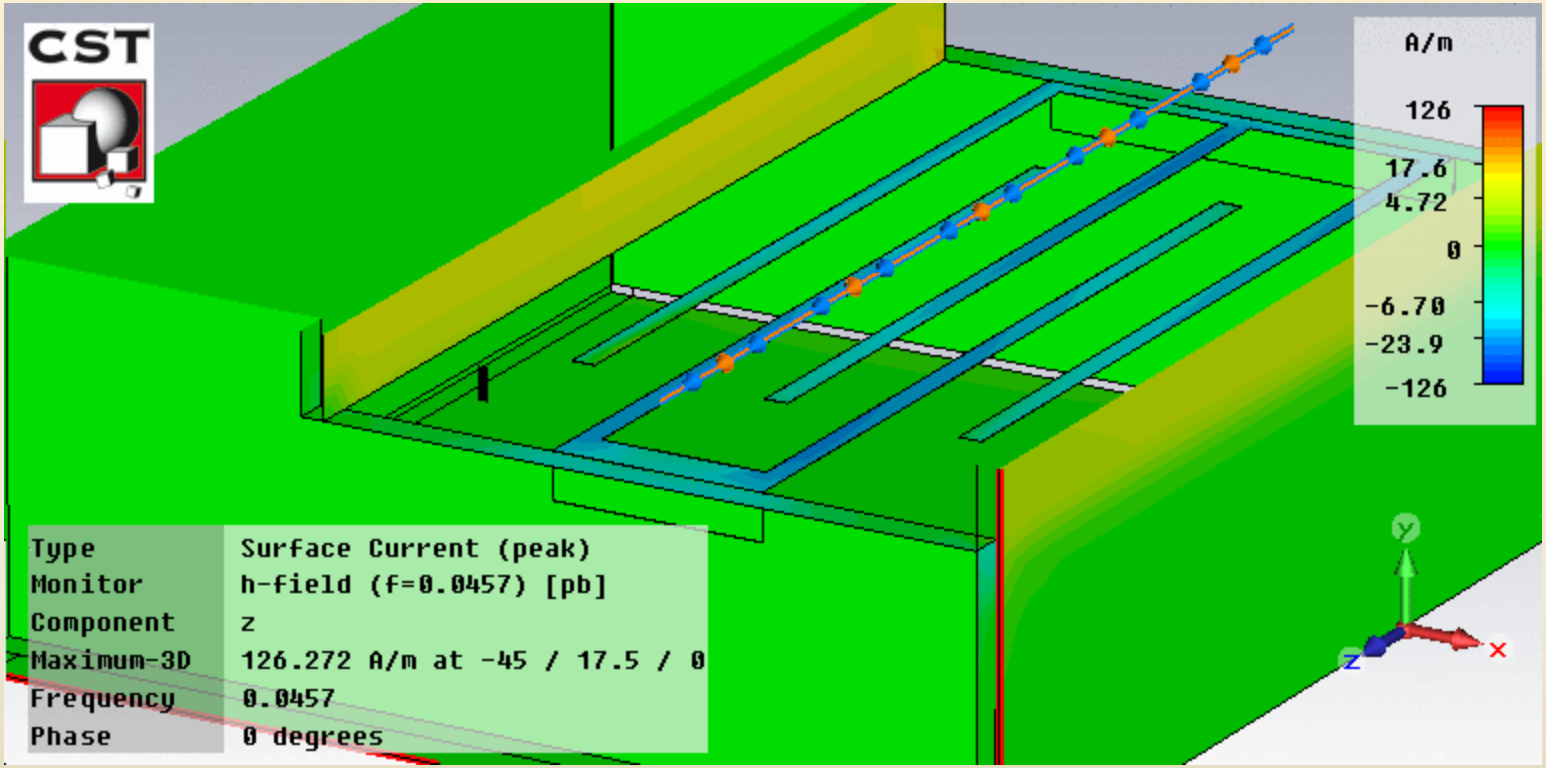
Comparing MKE with and without serigraphy



f=44 MHz

$$\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}\mu_{eff}}} \cong 0.78\ m \cong 4L_{finger}$$

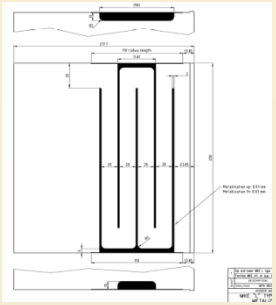
Comparing MKE with and without serigraphy



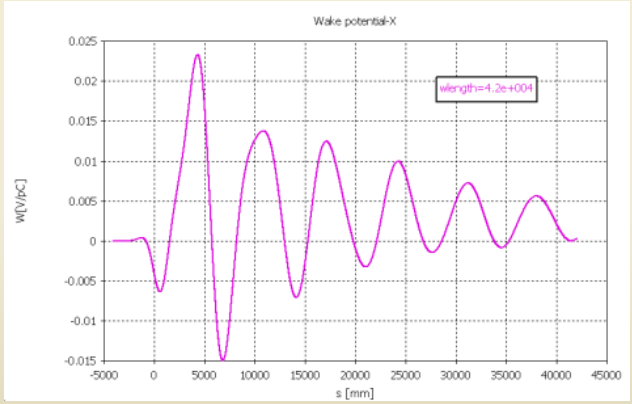
The simulation of the EM fields seems to confirm that we have a quarter-wavelength resonance

An accurate low frequency model

- Model of the serigraphy
  - Accounting finite conductivity



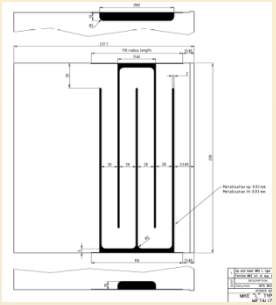
- Low frequency simulations
  - Longer bunch length



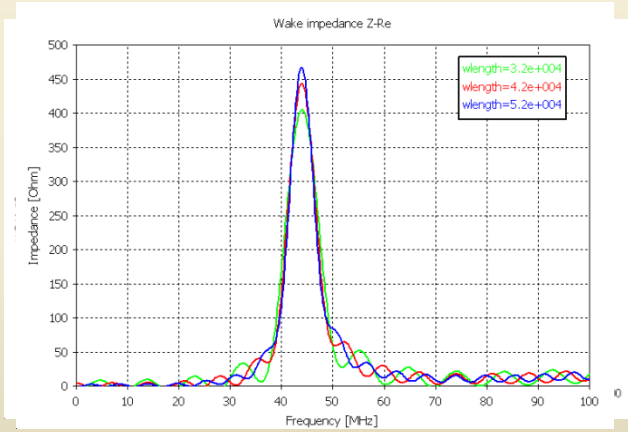
- Fit of the ferrite properties at low frequency

An accurate low frequency model

- Model of the serigraphy
  - Accounting finite conductivity

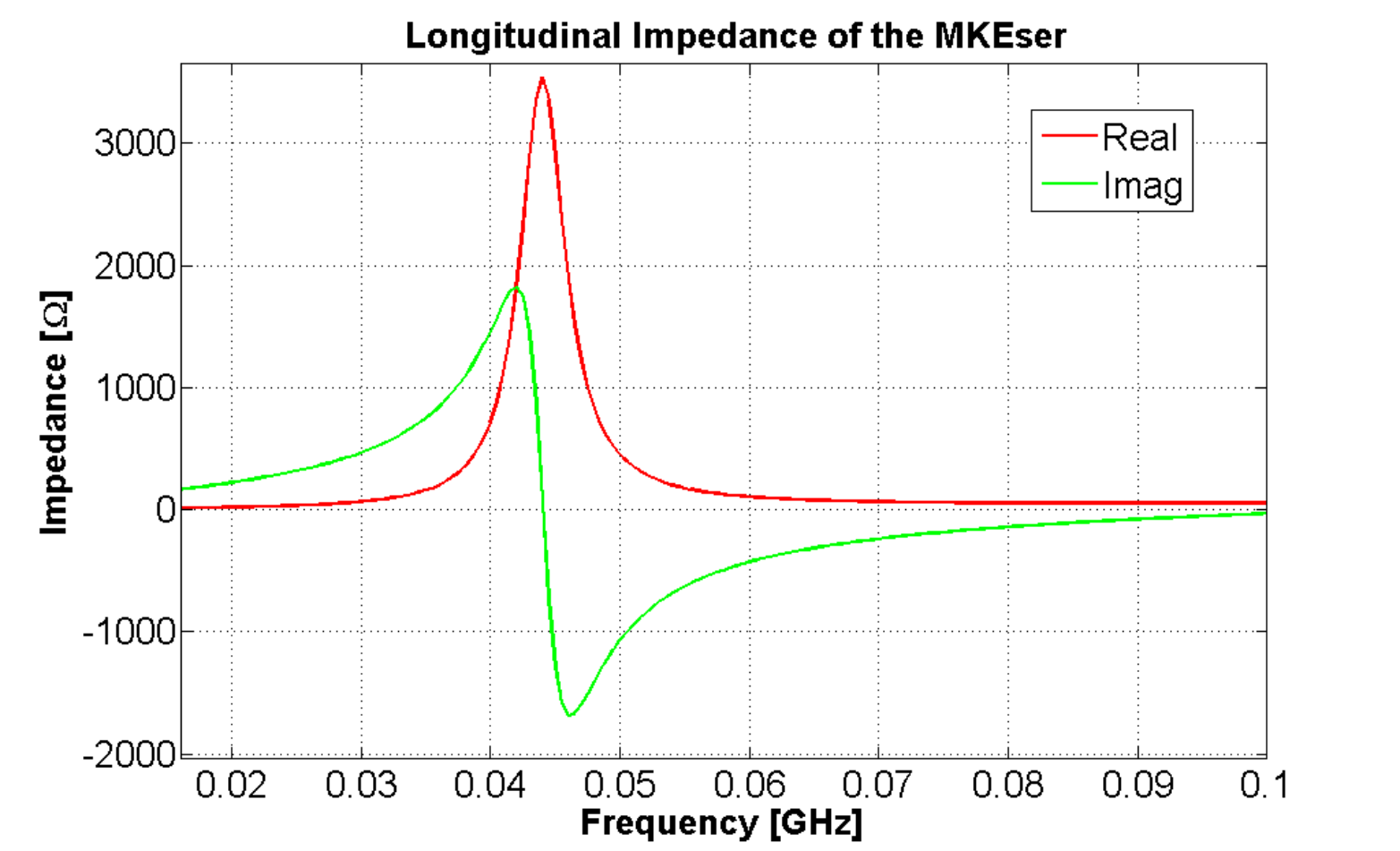


- Low frequency simulations
  - Longer bunch length
  - Studies of convergence



- Fit of the ferrite properties at low frequency

An accurate low frequency model



$$f_0 = 44\,MHz \quad Q = 10.5 \quad Z_{peak} = 3500$$

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Experimental confirmations

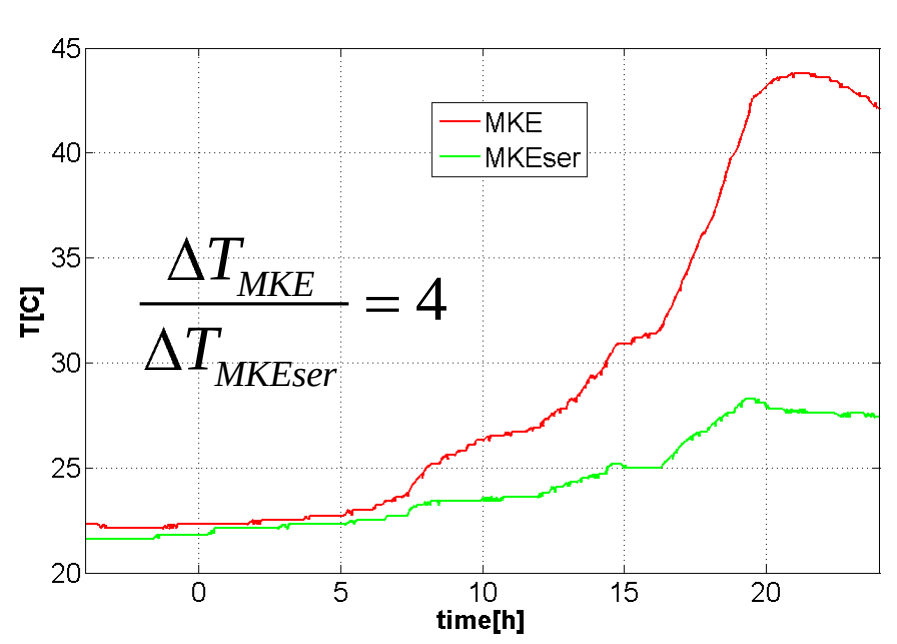
- The impedance model of the SPS extraction kicker can explain the beam induced heating observed in the SPS machine

C. Zannini, G. Rumolo. "MKE heating with and without seigraphy", Presented at the SPSU meeting, 2 August 2012, http://paf-spsu.web.cern.ch/paf-spsu/

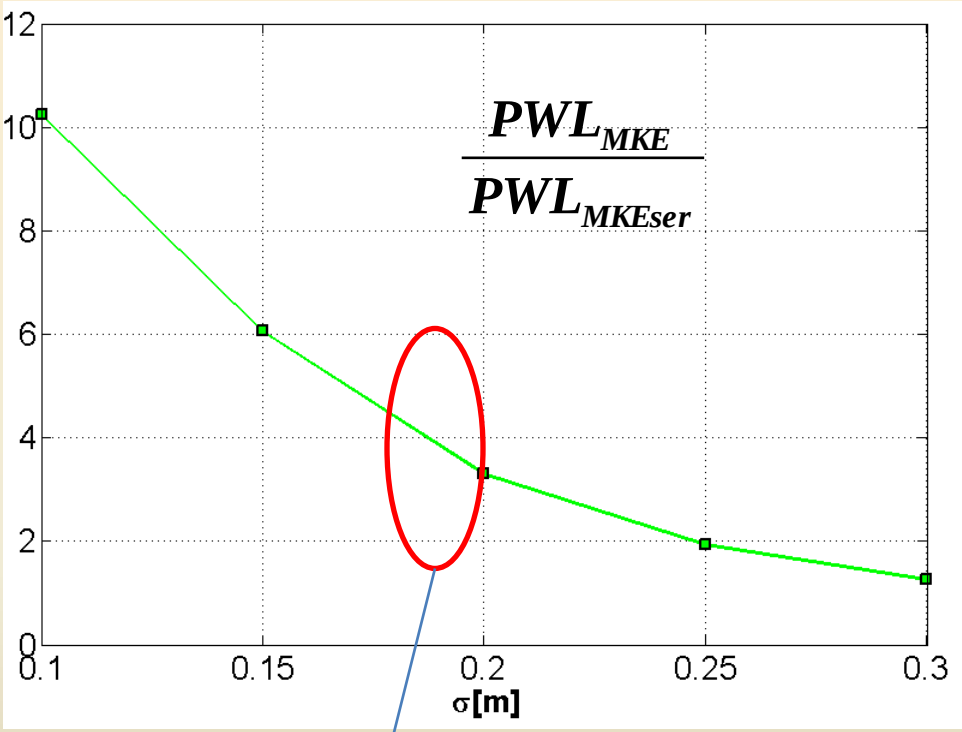
- Bench impedance measurements are in reasonable agreement with the impedance model

Experimental confirmations

Beam induced heating



Power loss from the impedance model



Bunchlength during the experiment

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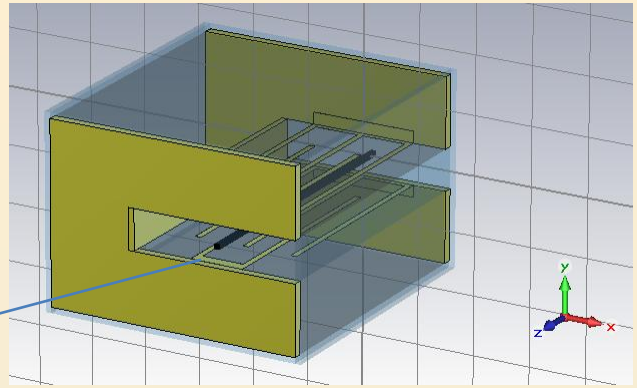
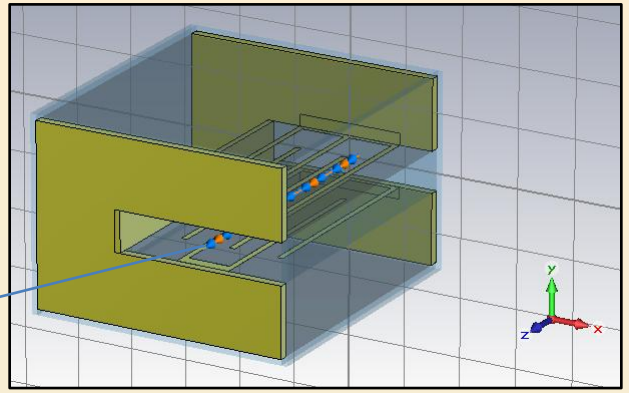
Comparing numerical measurements and simulations

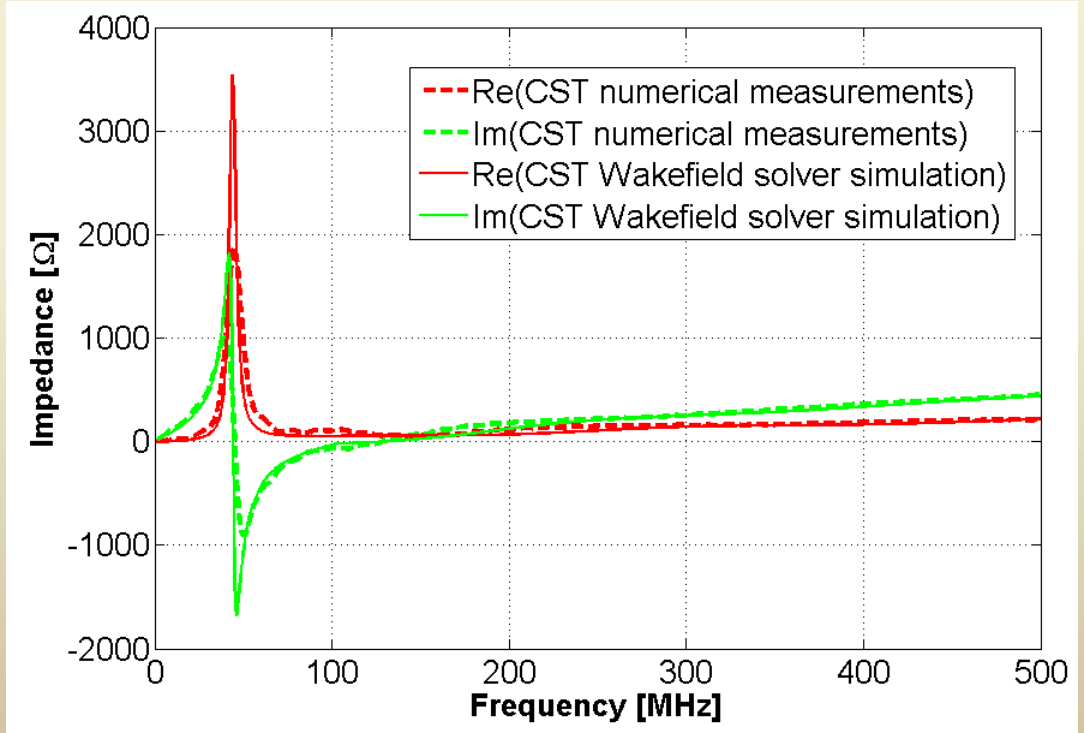


Simulation output: S21 and Zch

$$Z_{||} = -2Z_{ch}\, log\left(\frac{S_{21}}{S_{REF}}\right) \qquad S_{REF} = e^{-j\frac{2\pi fL}{c}}$$

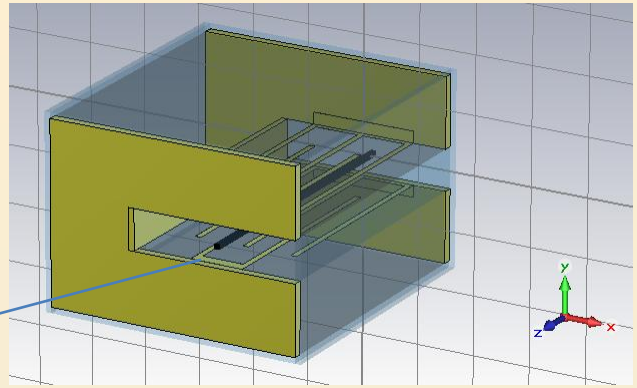


Simulation output: Impedance



Comparing numerical measurements and simulations

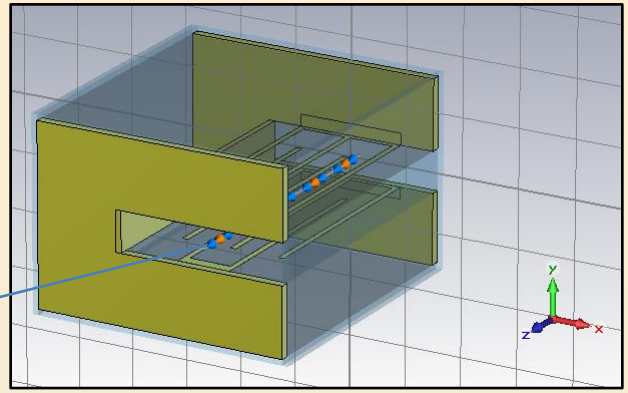
wire



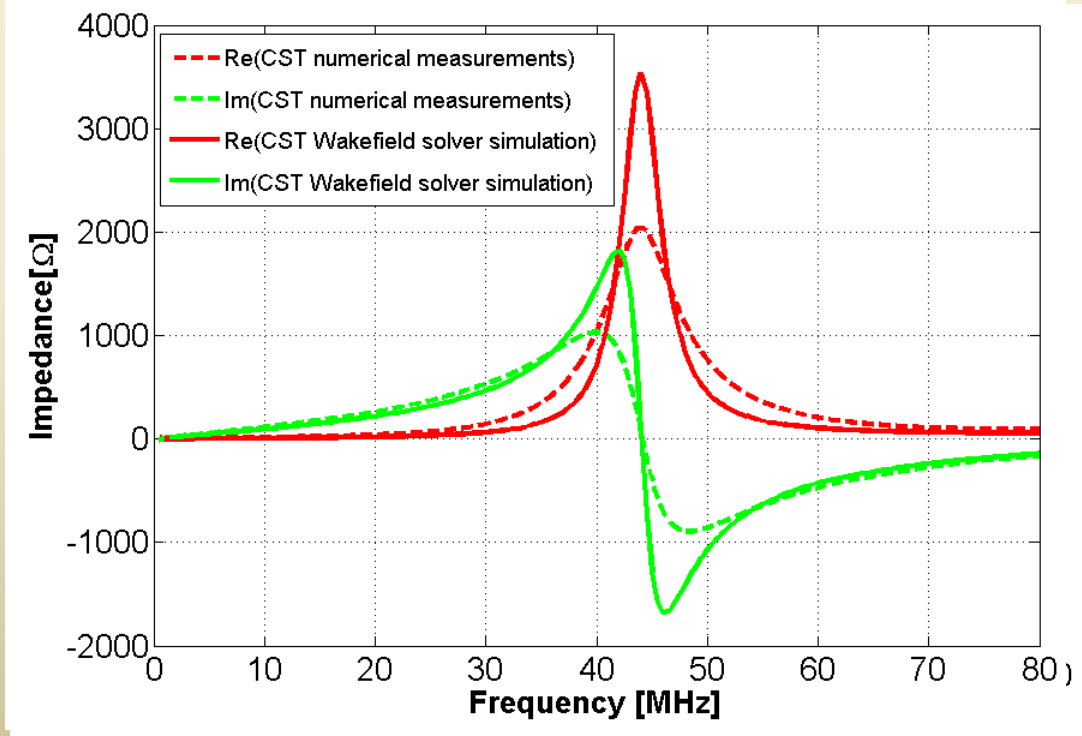
Simulation output: S21 and Zch

$$Z_{||} = -2Z_{ch}\, log\left(\frac{S_{21}}{S_{REF}}\right) \qquad S_{REF} = e^{-j\frac{2\pi fL}{c}}$$

beam



Simulation output: Impedance



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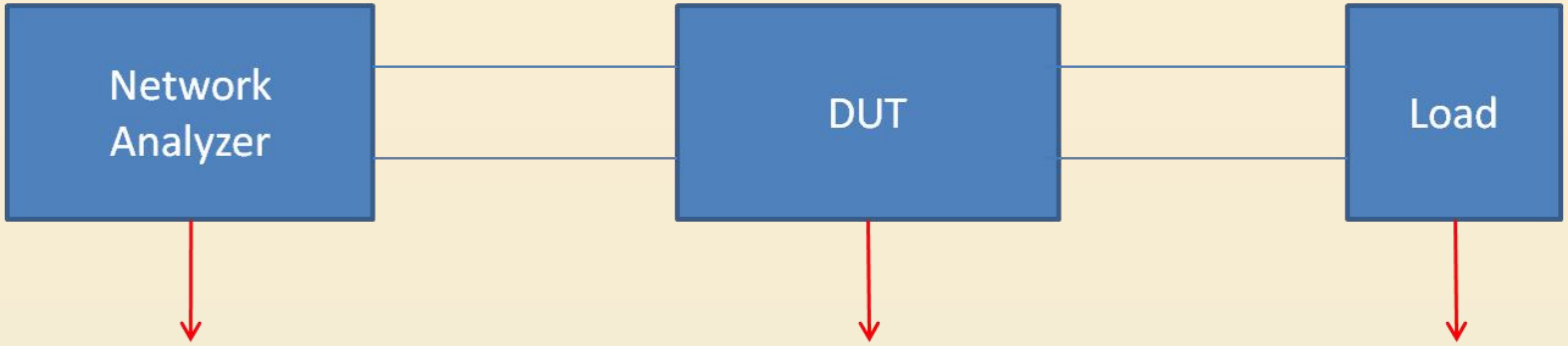
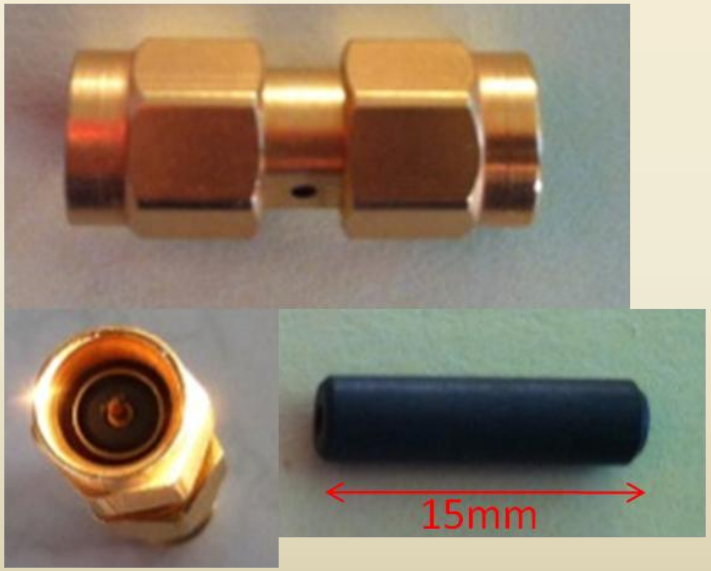
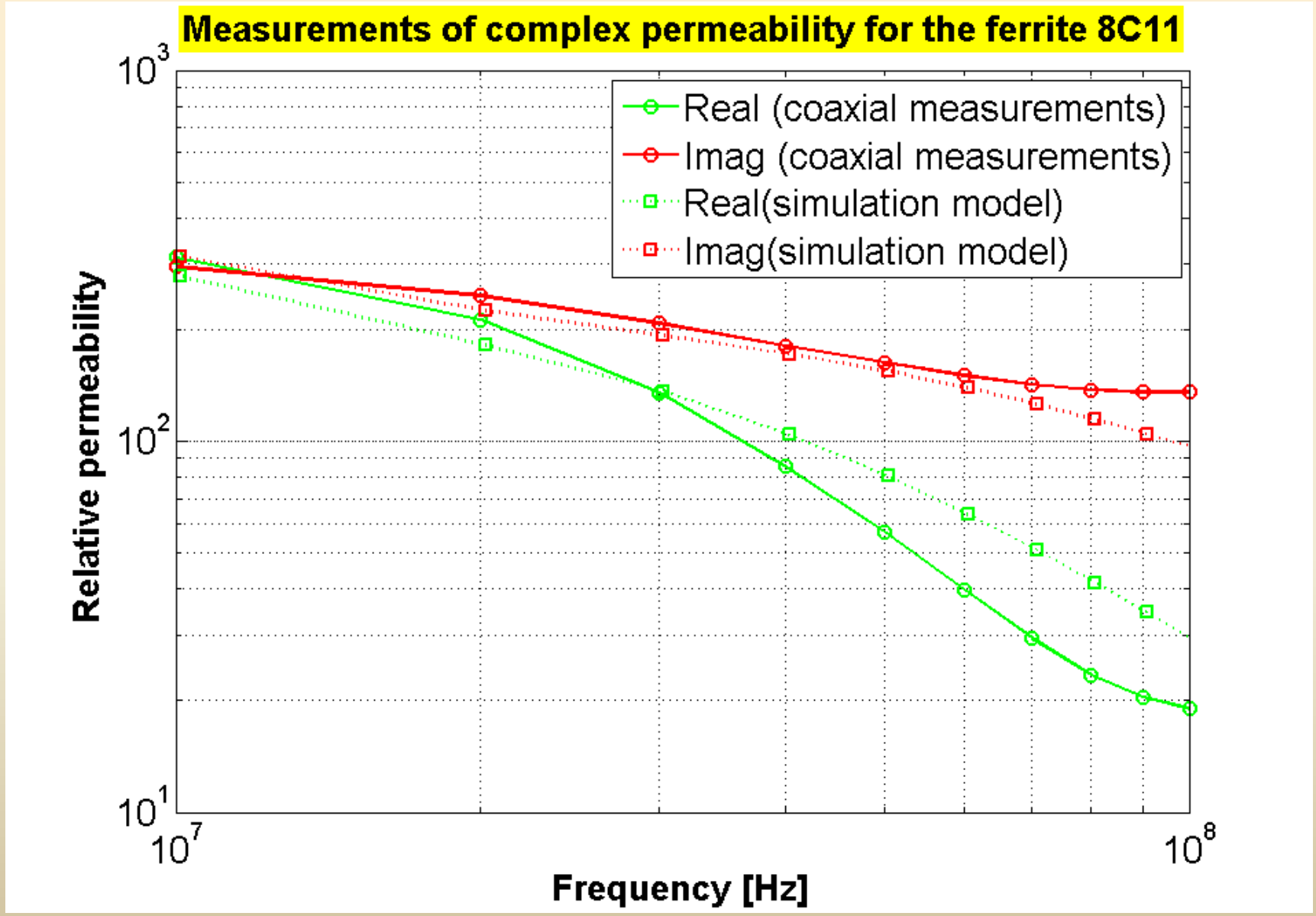
Coaxial line method: Measurement setup





G. De Michele, C. Zannini et al. "Broadband Electromagnetic characterization of materials for accelerator components", IPAC11, San Sebastian, Spain, 2011.

Ferrite permeability model



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- Using the CST Wakefield Solver the SPS kicker impedance contribution has been estimated.
- The results were successfully benchmarked with analytical models and beam induced heating observations
- A numerical investigation of coaxial wire measurements has been presented
- Ferrite measurements were performed to validate the complex permeability model used in CST 3D EM simulations

Thank you for your attention