Wakefield calculations with PBCI

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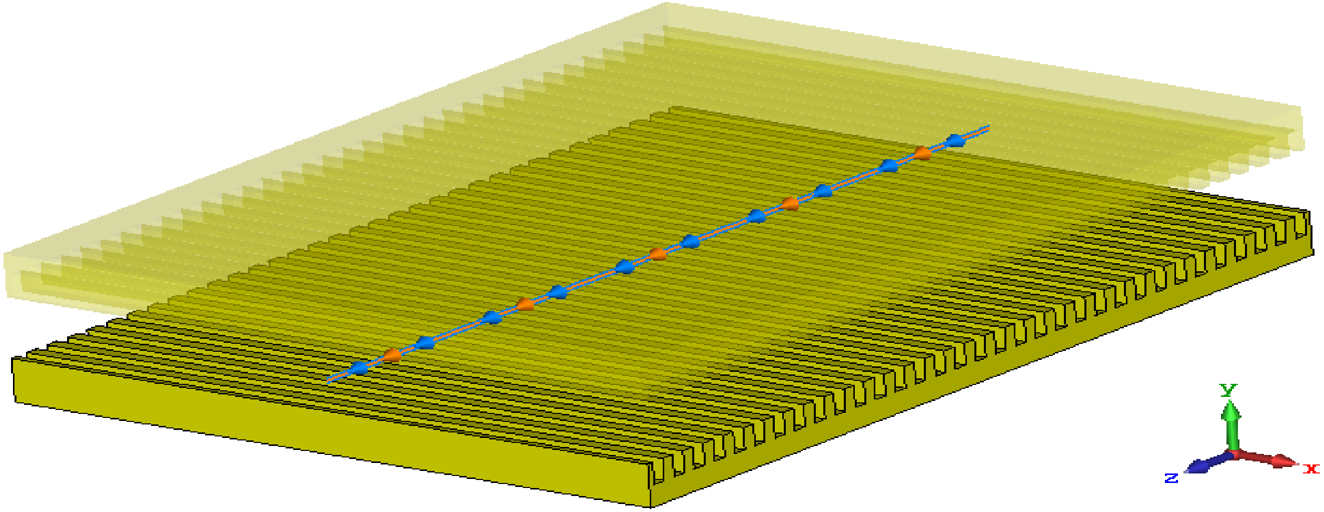
- Recent wakefield/impedance calculations
  - Joule losses in bunch dechirper
  - LHC RF fingers
  - Accelerator on chip
- New developments with the PBCI code
  - Dielectric materials
  - Surface impedance model
  - Absorbing boundary conditions
- Summary

Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

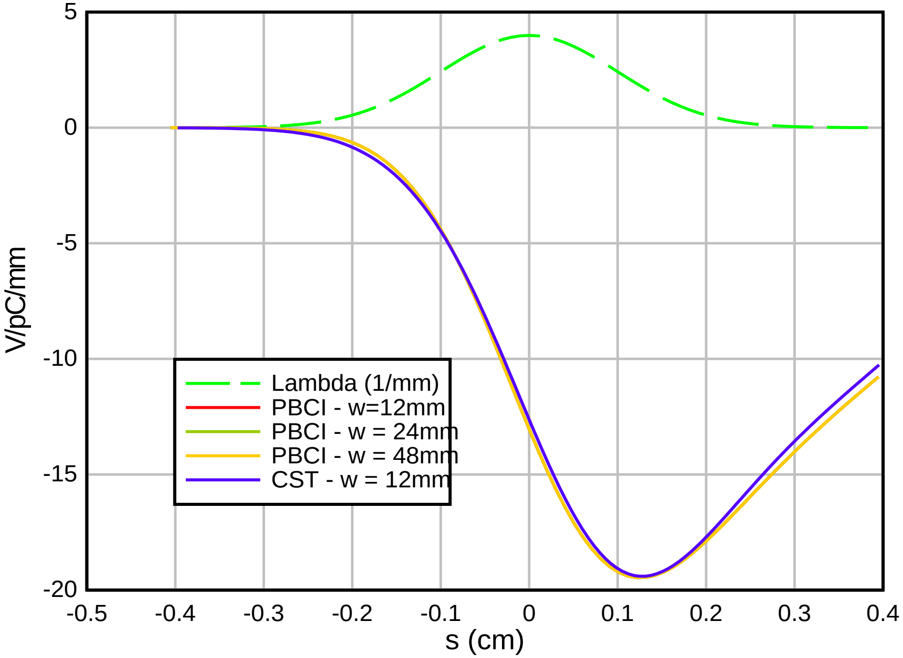
Period, p	0.5 mm
Longitudinal gap, t	0.25 mm
Full depth, h	0.5 mm
Nominal half aperture, a	0.7 mm
Width, w	**variable, 1.5 – 48 mm**
Material	lossy metal (Al), $\kappa_0 = 3.56 \cdot 10^7 S/m$



Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

Bunch length	**100um**
Width, w	variable, 12 – 48mm
Calculation method	CST, PBCI, theory



Method - dechirper width	**Loss factor (V/pC/mm)**
PBCI – w = 12mm	11.97
PBCI – w = 24mm	11.97
PBCI – w = 48mm	11.97
CST – w = 12mm	11.79
Theory – w = 12mm	14.5

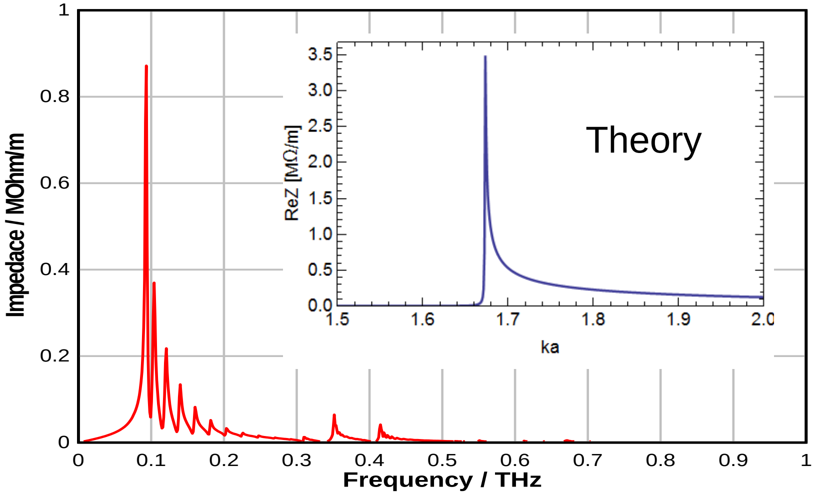
1) CST and PBCI agree very well.
2) CST uses free space boundary conditions; in PBCI, the structure is closed by lateral PEC walls. For w >= 12mm, boundary conditions play no role in the short range.
3) Theoretical estimation is 18% off

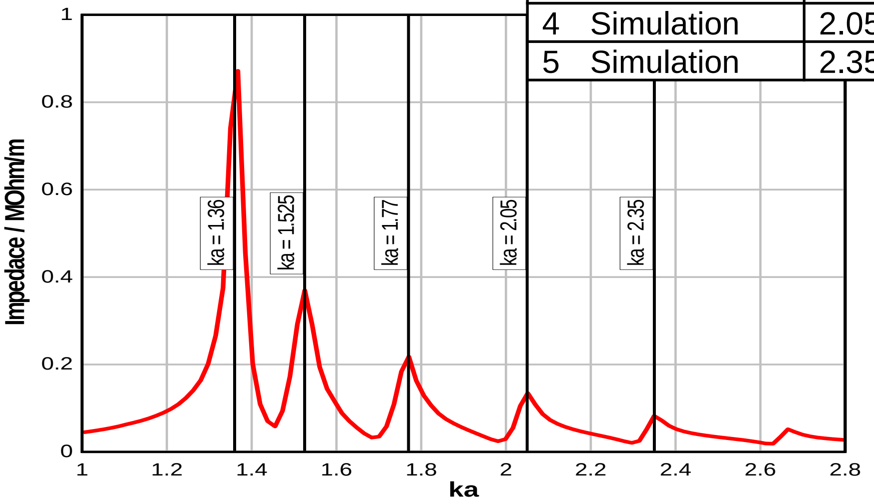
Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

Bunch length	**100um**
Width, w	12mm
Calculation method	CST, theory

Resonance no.		**ka**
1	**Theory**	**1.67**
	Simulation	1.36
2	Simulation	1.52
3	Simulation	1.77
4	Simulation	2.05
5	Simulation	2.35



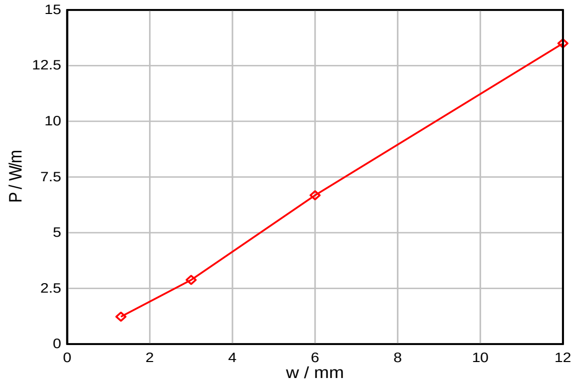


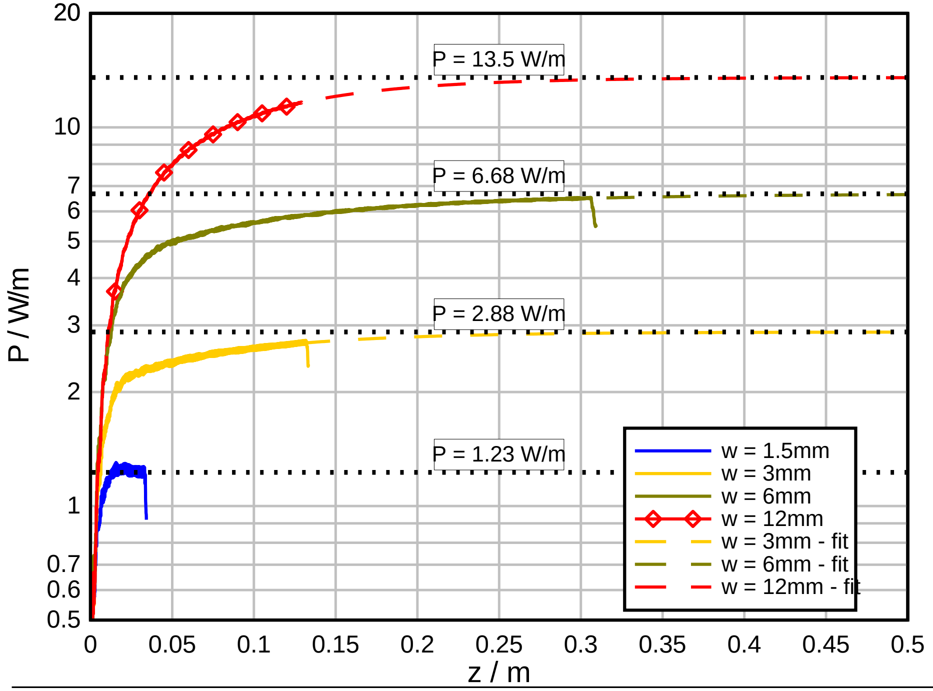
1) The main resonance peak predicted by theory is shifted to higher frequencies by ~23% compared to simulations.
2) Very good agreement with the mode matching method (Zhang et. al, 2015)

Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

Bunch length	**100um**
Bunch charge	0.3nC
Repetition rate	100kHz
Width, w	**variable, 1.5 – 12mm**
Calculation method	CST





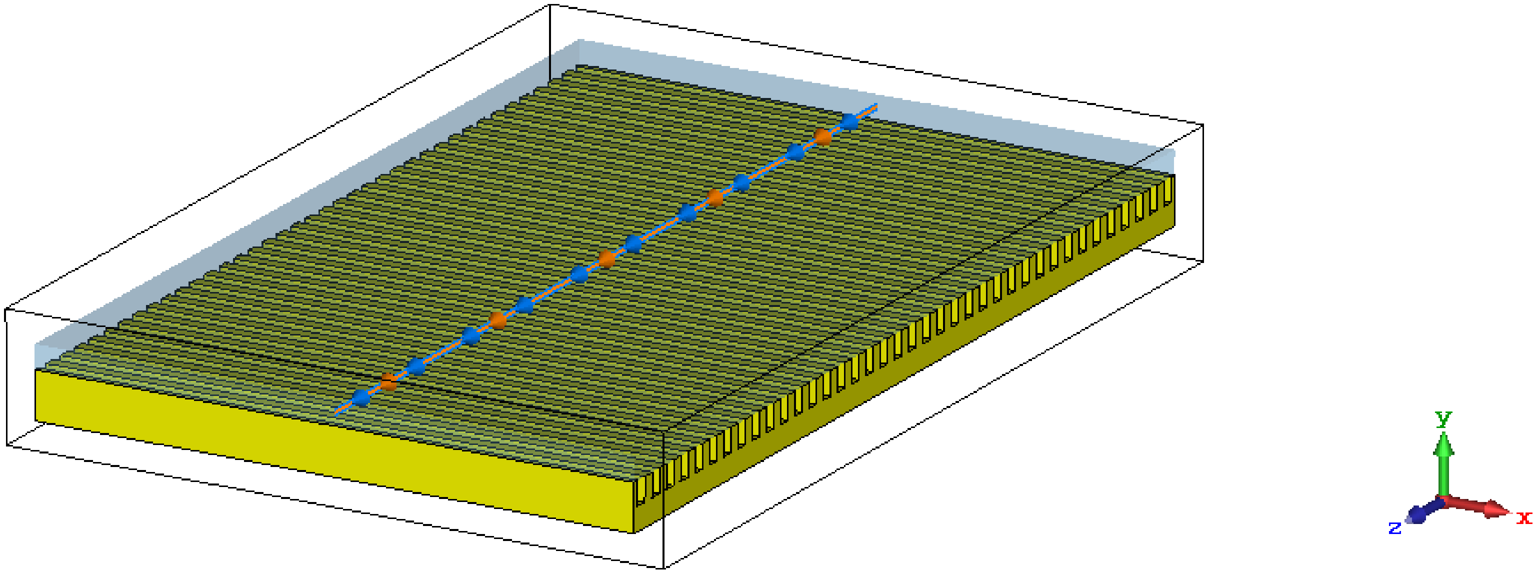
1) Joule losses could be calculated only for a bunch length 100um
2) The results are reliable up to w=6mm; for w=12, steady state loss is obtained by extrapolation.
3) Computed losses are by a factor ~2 higher than predicted by theory

Dechirper width, w / mm	**Joule loss / W/m**
1.3	1.23
3	2.88
6	6.68
12	13.5
12 - theory	6

Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

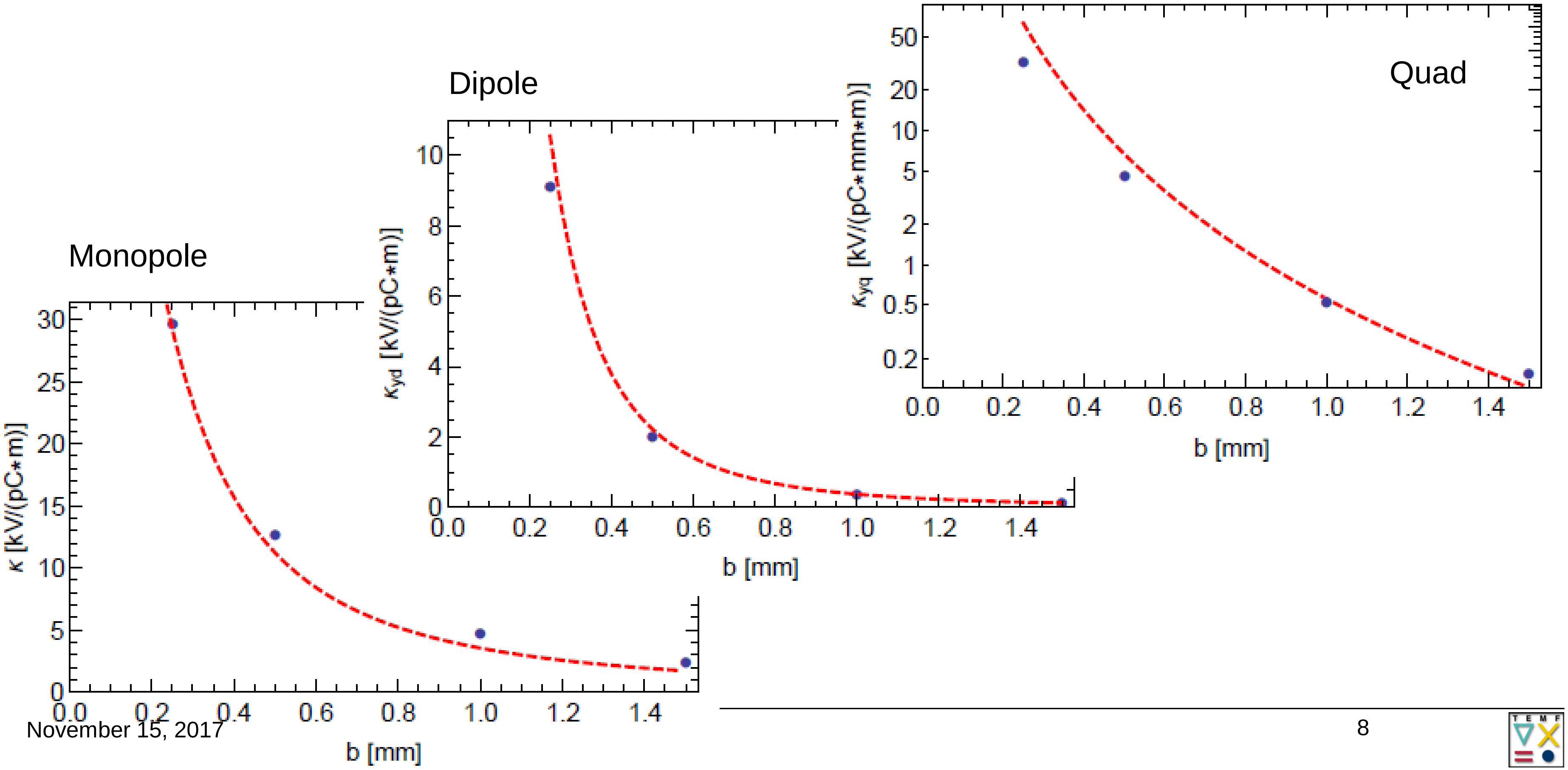
Period, p	0.5 mm
Longitudinal gap, t	0.25 mm
Full depth, h	0.5 mm
Width, w	12mm
Length, L	variable, 10 – 408mm
Material	lossy metal (Al), $\kappa_0 = 3.56 \cdot 10^7 S/m$



Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

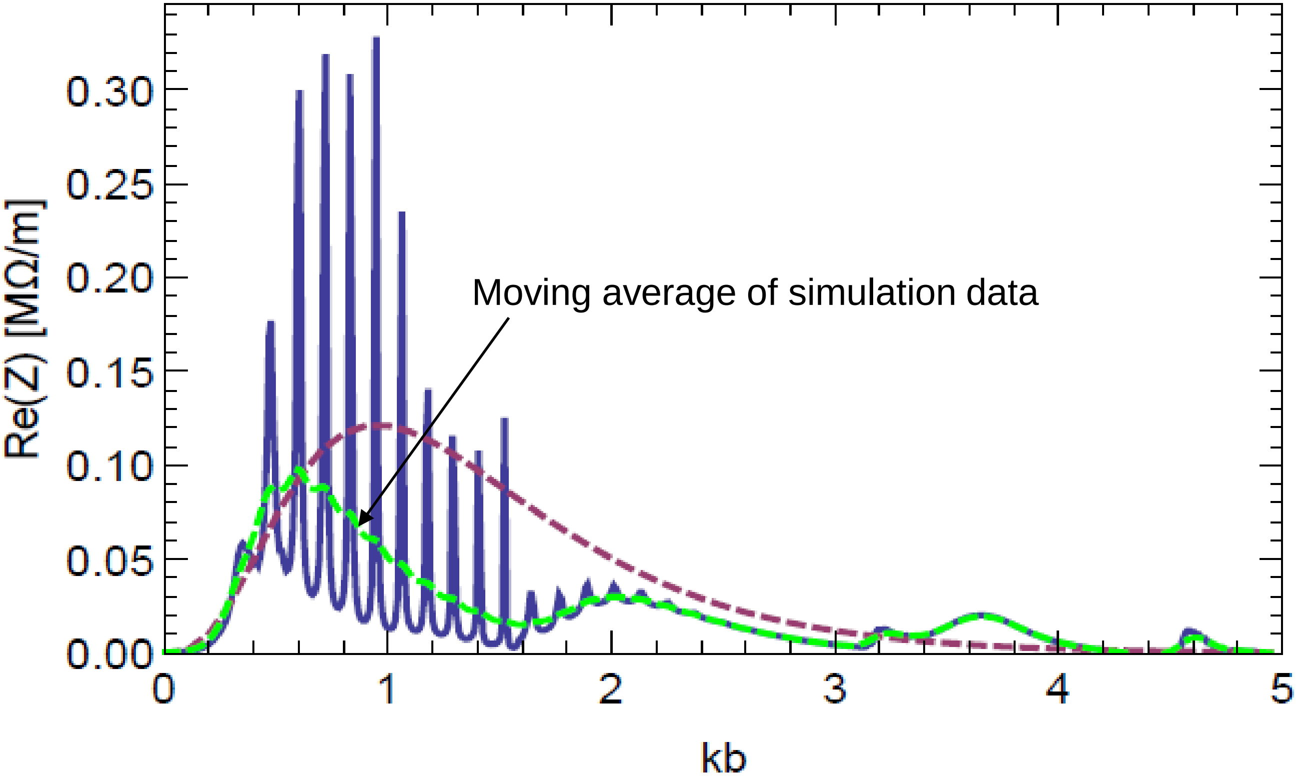
Comparison of theory and simulation for the loss/kick factors for different beam distances



Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

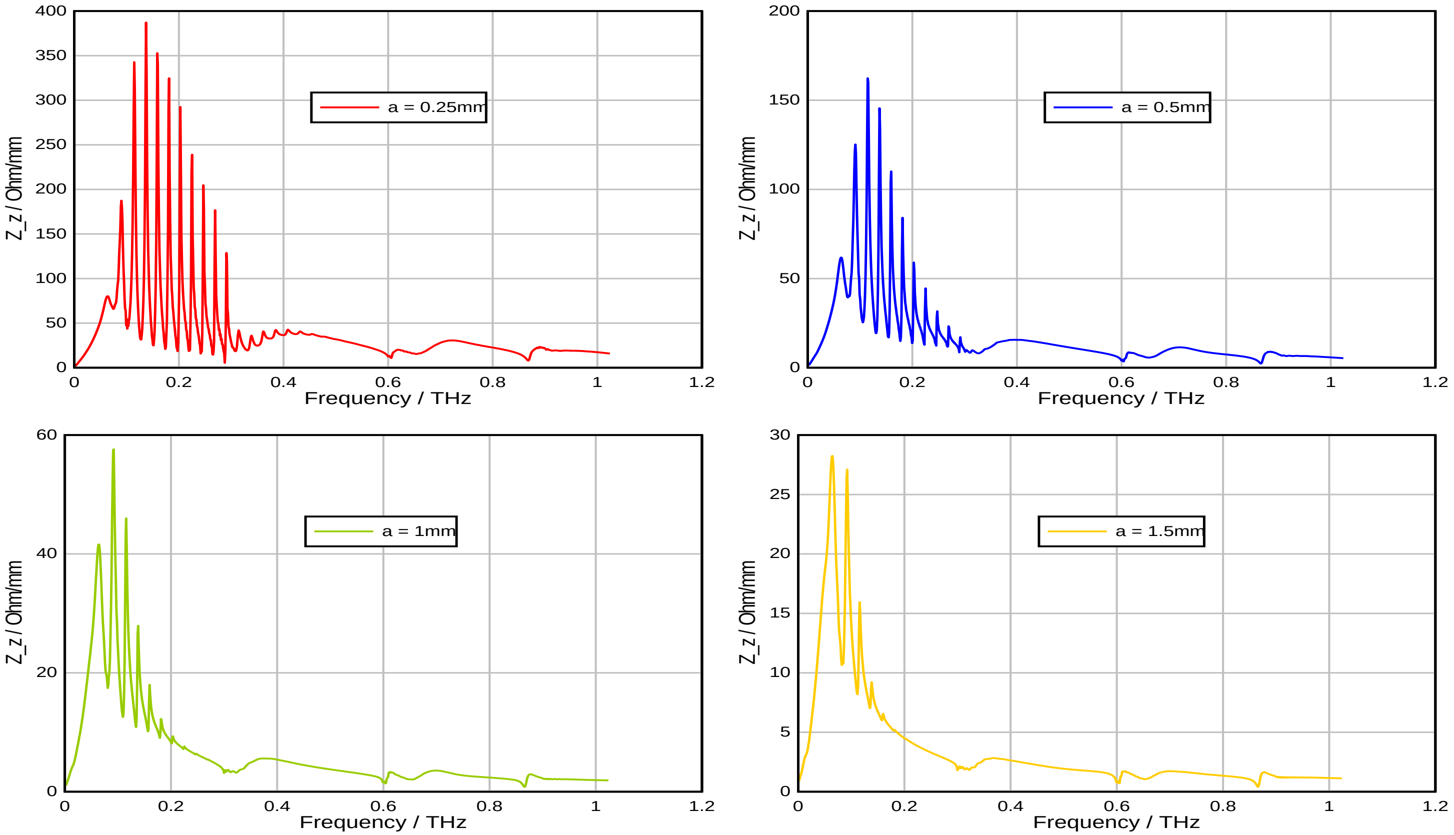
Comparison of theory and simulation for longitudinal impedannce a=1.5mm



Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)

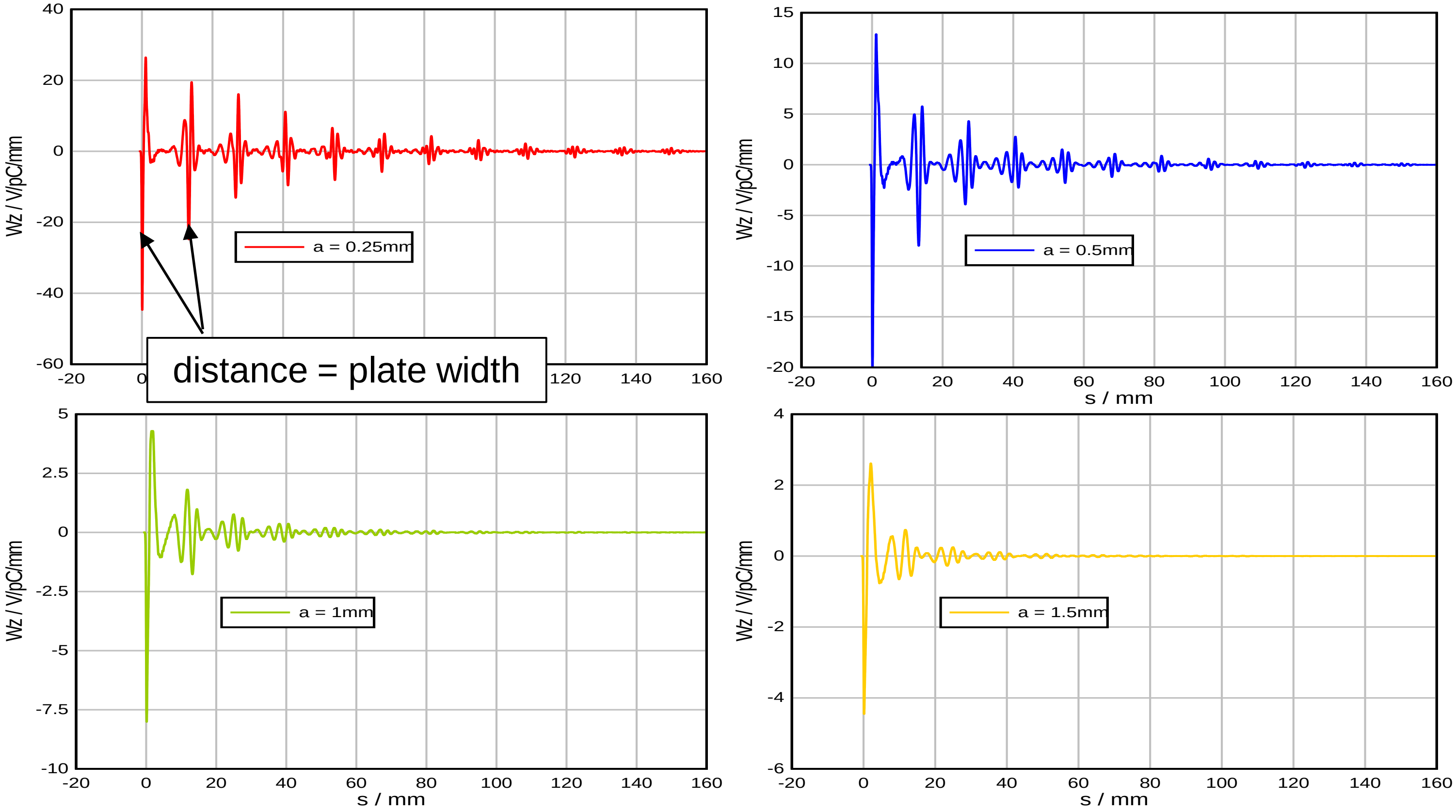
Longitudinal beam impedance for different beam distances, a=0.25 – 1.5mm (top/left to bottom/right)



Recent wakefield/impedance calculations

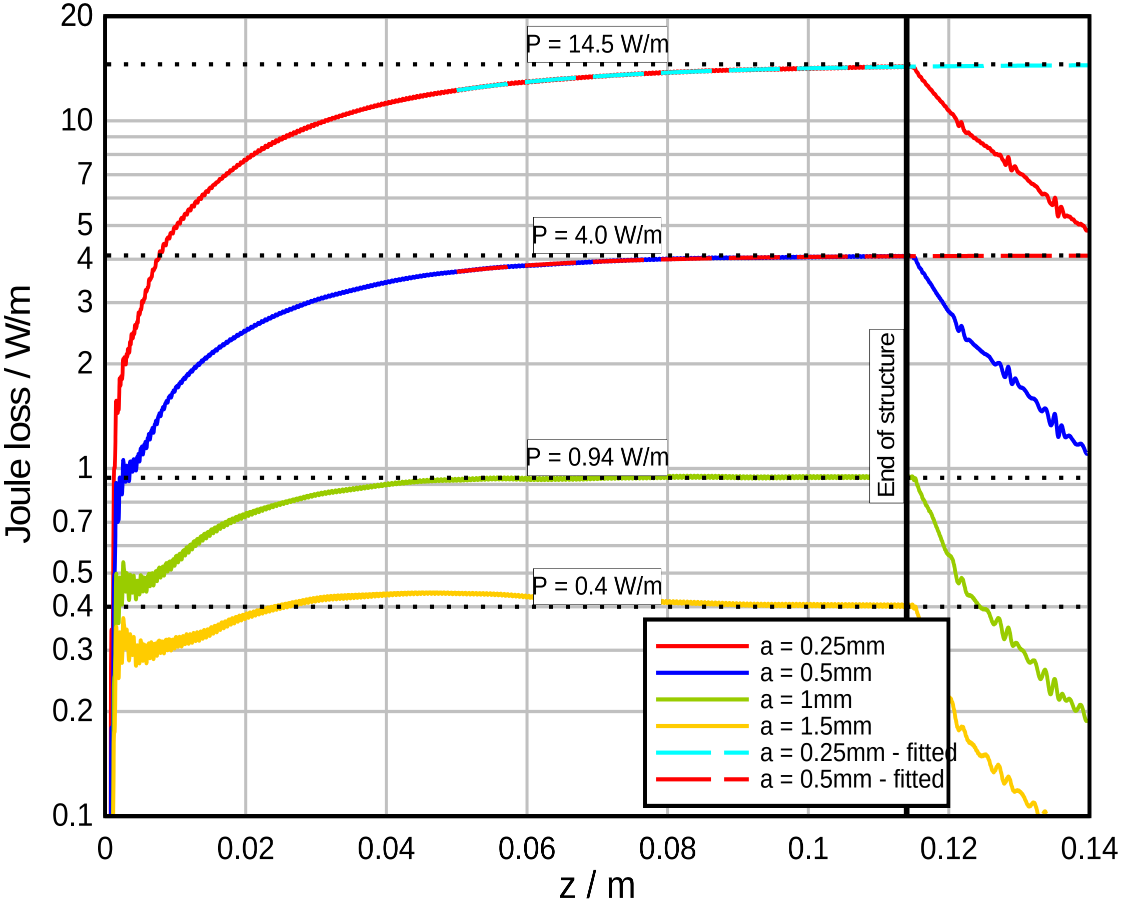
- Bunch dechirper (with K. Bane, G. Stupakov)

Longitudinal wake potentials for different beam distances, a=0.25 – 1.5mm (top/left to bottom/right)

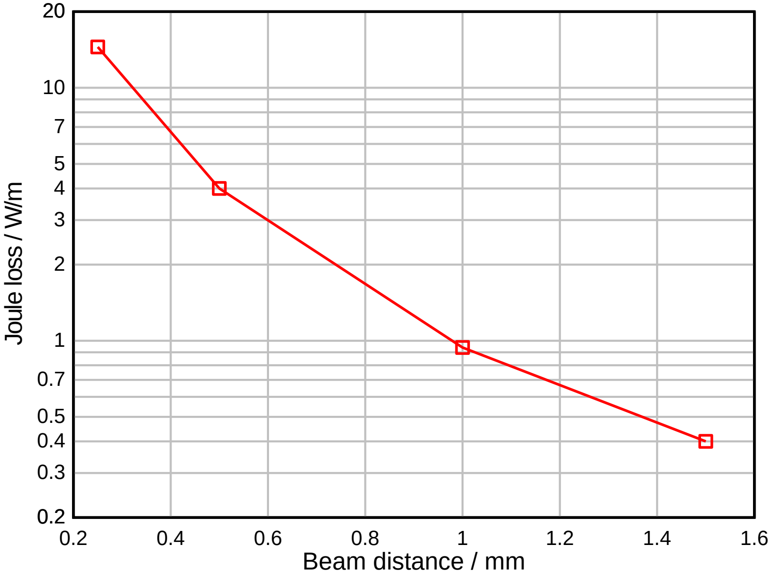


Recent wakefield/impedance calculations

- Bunch dechirper (with K. Bane, G. Stupakov)



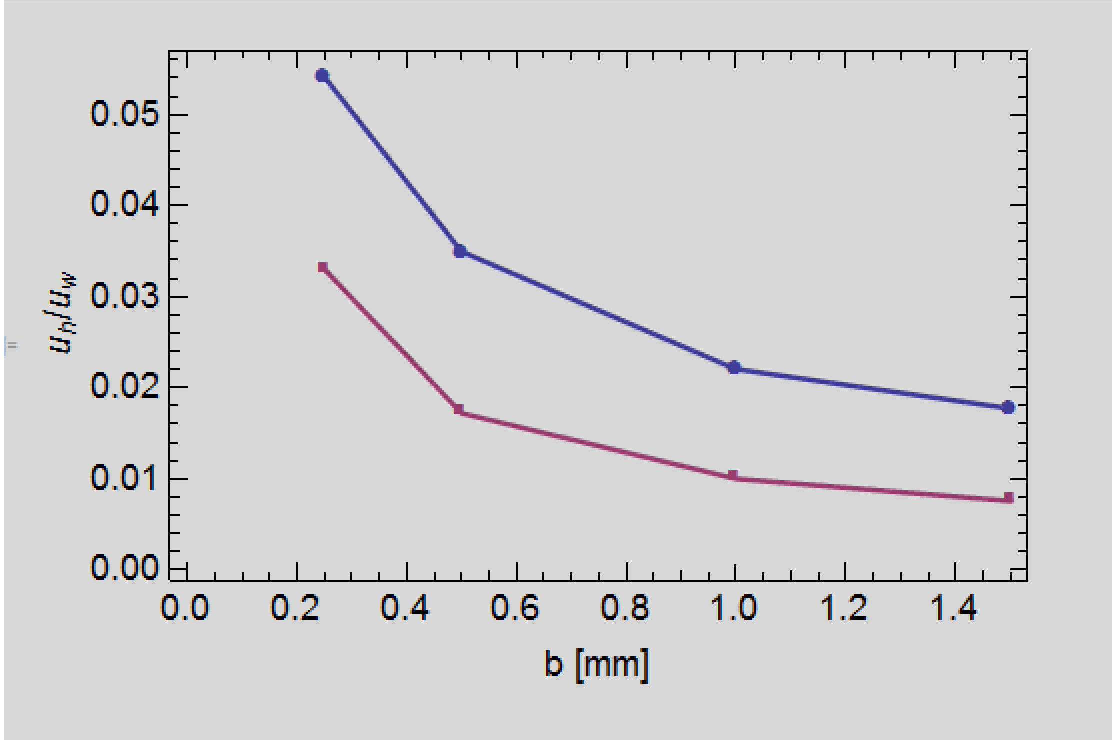
Total Joule losses vs. beam-plate distance (bunch: 100um, w=12mm)



Recent wakefield/impedance calculations

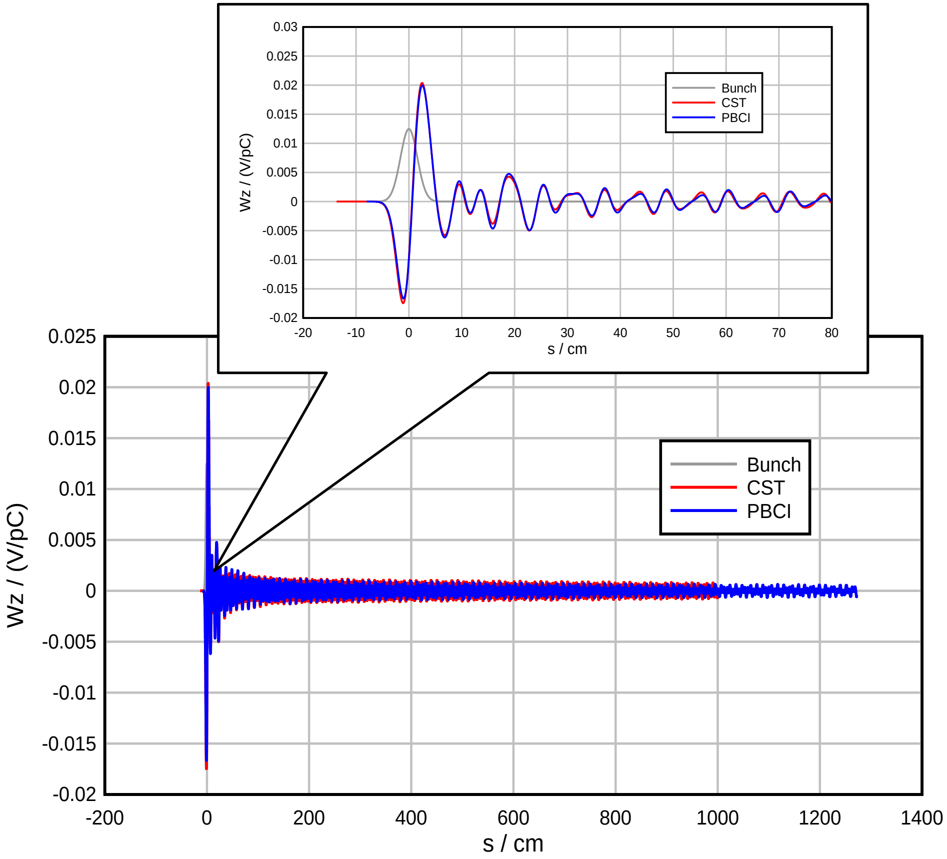
- Bunch dechirper (with K. Bane, G. Stupakov)

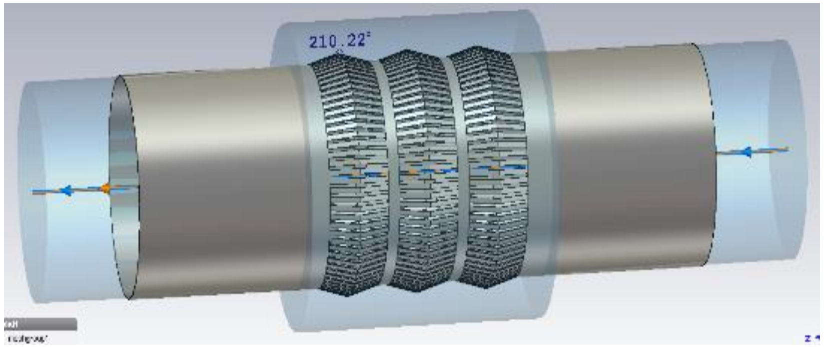
Joule losses for the single plate are a factor 2 higher than predicted by theory

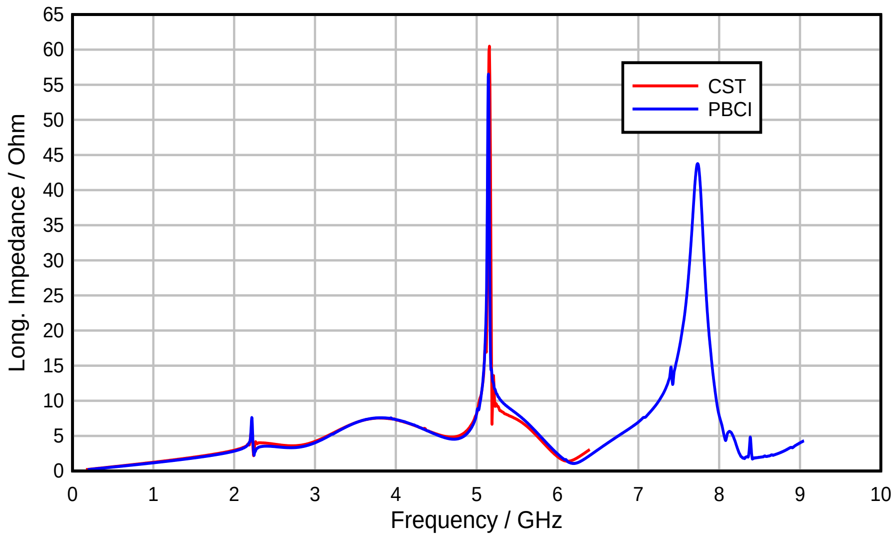


Recent wakefield/impedance calculations

- LHC RF-Fingers (with E. Metral, U. Niedermeier)







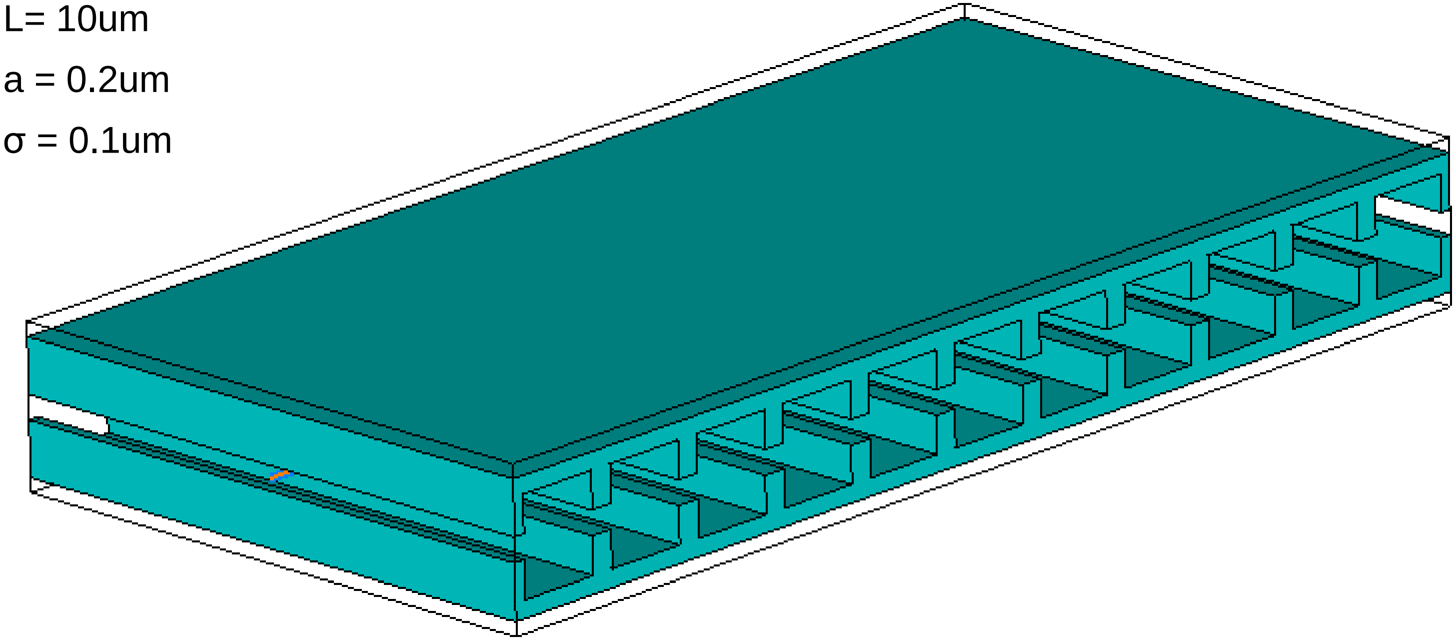
Recent wakefield/impedance calculations

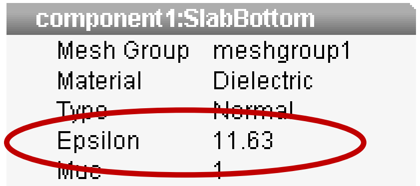
- ACHIP-cell (with U. Niedermeier, O.-B. Frankenheim)

L= 10um

a = 0.2um

σ = 0.1um



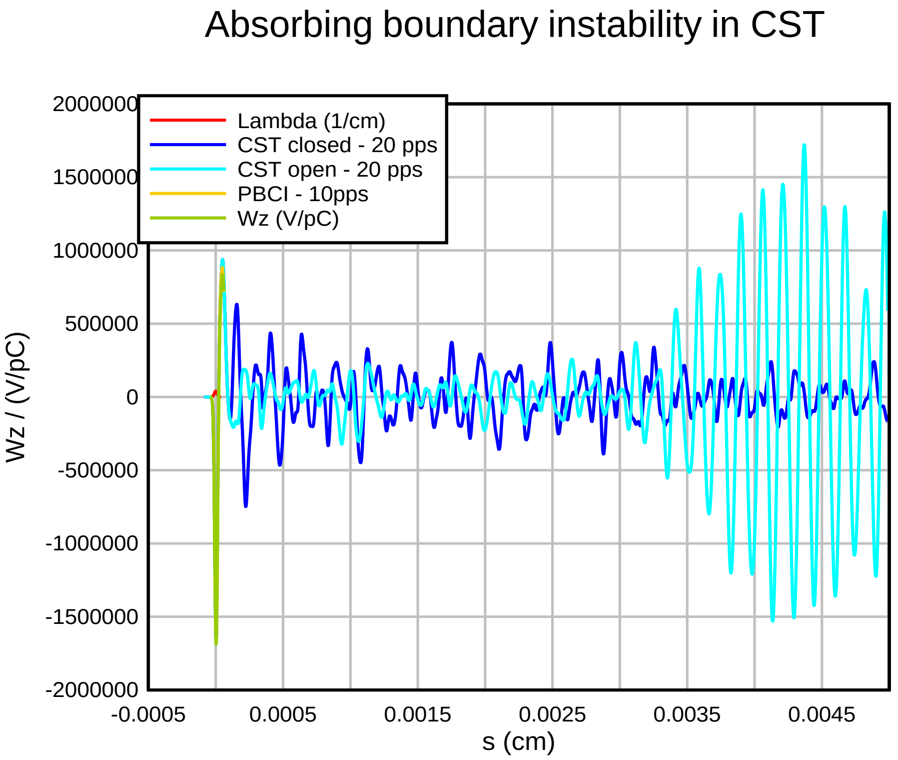


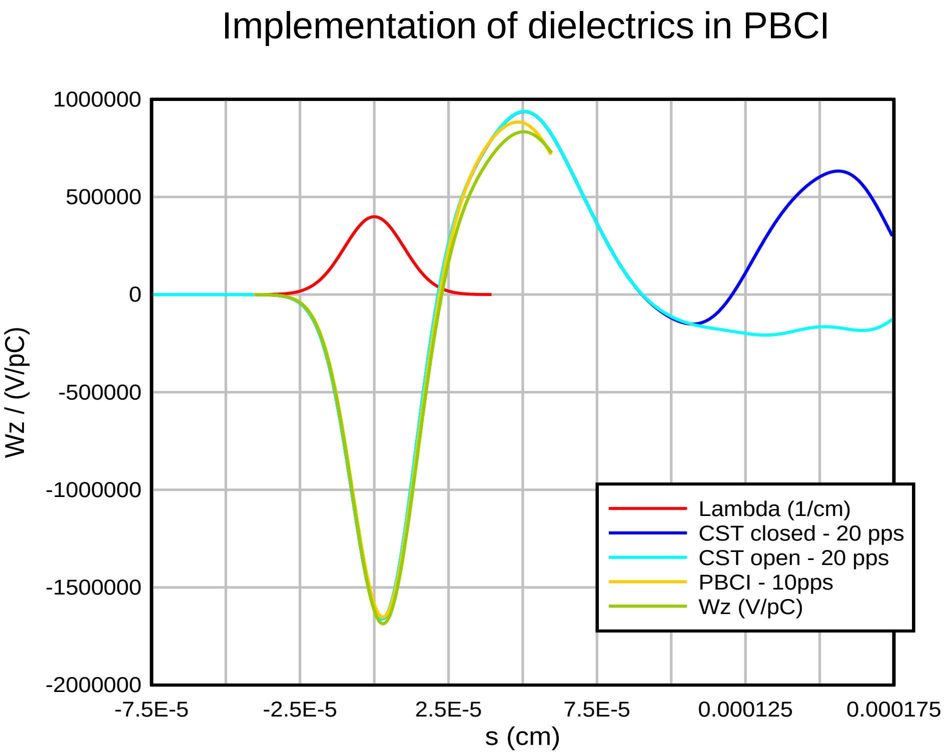
component1:SlabBottom

Mesh Group	meshgroup1
Material	Dielectric
Type	Normal
Epsilon	11.63
Mue	1

Dielectric structures

- ACHIP-cell (with U. Niedermeier, O.-B. Frankenheim)


Absorbing boundary instability in CST


Implementation of dielectrics in PBCI

Surface impedance models

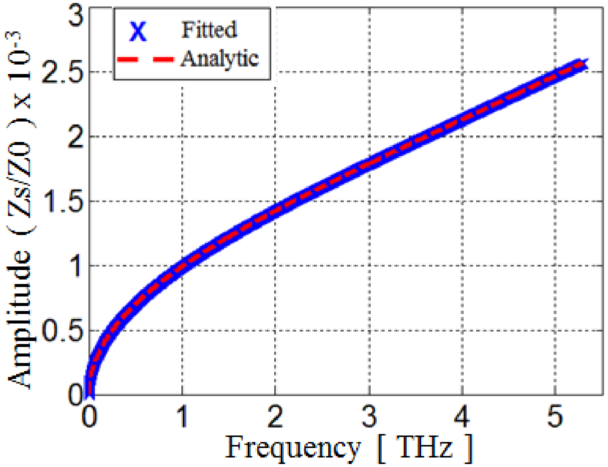
- Vector fitting of surface impedance functions

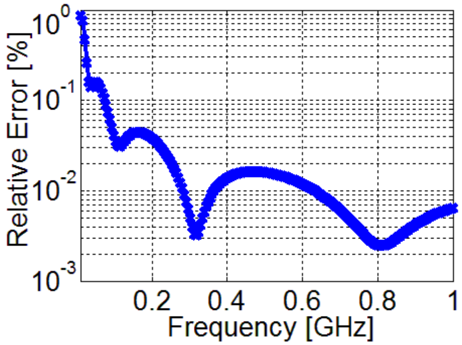
$$\boxed{\vec{E}_\tau\ (\omega) = Z_s(\omega)\ [\vec{n} \times \vec{H}_\tau(\omega)]} \Rightarrow \boxed{Z_s\ (\omega) = j\omega L + \alpha_0 + \sum_{i=1}^{Np} \frac{\alpha_i}{j\omega + \beta_i}}$$

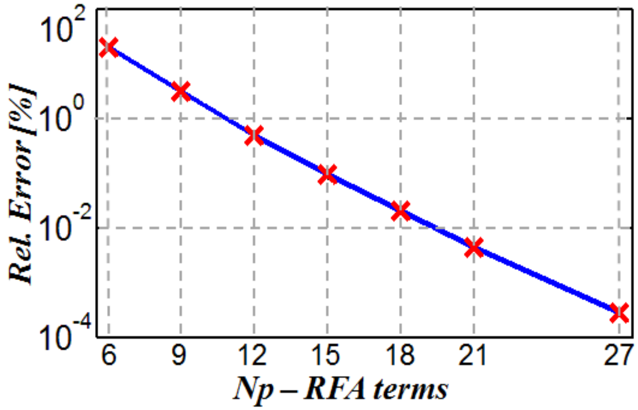
Pole-residue representation

- The case of resistive wall impedance: $Z_s(\omega) \cong \sqrt{\dfrac{j\,\omega\,\mu}{\sigma(\omega) + j\,\omega\,\varepsilon}}$

Example : Cu – N=21, ~ 10MHz-5THz, Δf~5MHz







Surface impedance models

- Auxiliary Differential Equation (ADE) formulation

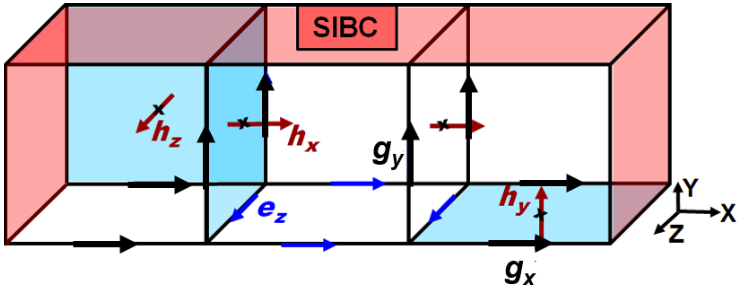
$$\vec{n} \times \vec{E}(t) = L \cdot \frac{d}{dt}\left[\vec{n} \times \vec{n} \times \vec{H}(t)\right] + \sum_{i=0}^{Np} \vec{n} \times \vec{G}_i(t)$$

$$\boxed{\begin{aligned} &\vec{n} \times \vec{G}_0 = \alpha_0 \, [\vec{n} \times \vec{n} \times \vec{H}] \\ &\frac{d}{dt}\vec{n} \times \vec{G}_i + \beta_i \vec{n} \times \vec{G}_i = \alpha_i \, [\vec{n} \times \vec{n} \times \vec{H}] \end{aligned}}$$

set of ADE for magnetic “surface currents” (Woyna, Gjonaj, 2014)

  - Modified discrete Maxwell’s equations:

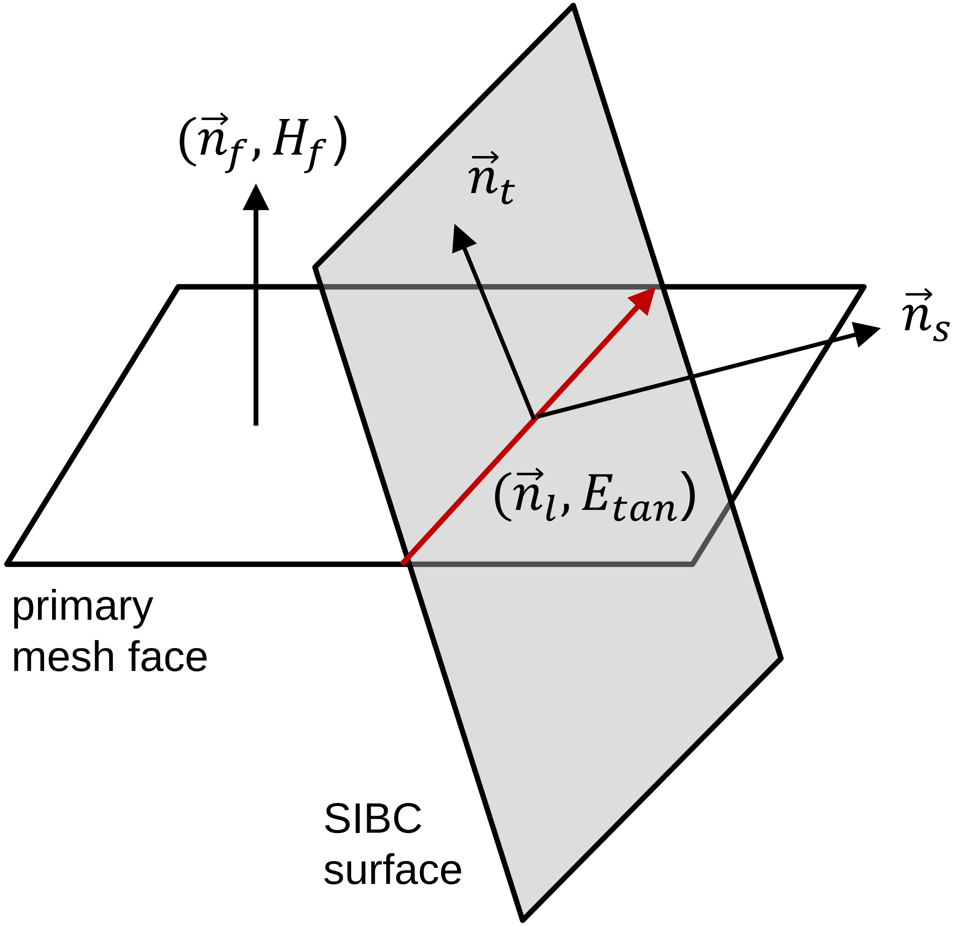
$$\boxed{\frac{d}{dt}\begin{pmatrix} \widehat{e} \\ \widehat{h} \\ 0 \\ g_0 \\ \vdots \\ g_N \end{pmatrix} = \begin{pmatrix} 0 & M_\varepsilon^{-1}C^T & 0 & 0 & \cdots & 0 \\ -M_\mu^{-1}C & 0 & C_B & C_B & \cdots & C_B \\ 0 & \alpha_0 & 1 & 0 & \cdots & 0 \\ 0 & -\alpha_1 & 0 & \beta_1 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & -\alpha_N & 0 & 0 & \cdots & \beta_N \end{pmatrix} \begin{pmatrix} \widehat{e} \\ \widehat{h} \\ g_0 \\ g_1 \\ \vdots \\ g_N \end{pmatrix}}$$



allocation of SIBC currents on grid

Surface impedance models

- Approximation of curved PEC boundaries



$$E_{tan} = Z(\omega)\vec{n}_l \cdot (\vec{n}_s \times \vec{H}_{tan}) = \dots$$

$$E_{tan} = Z(\omega)\frac{\vec{n}_l \cdot (\vec{n}_s \times \vec{n}_t)}{\vec{n}_f \cdot \vec{n}_t} H_f$$

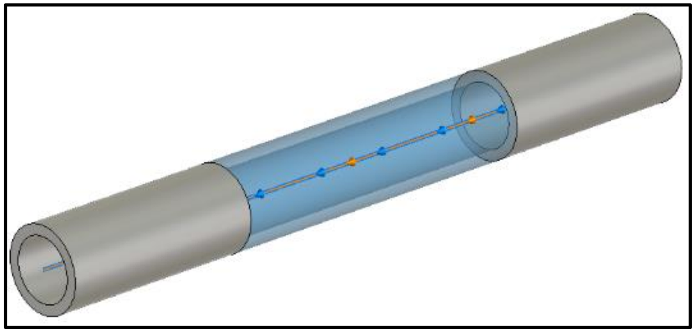
correction factor using SIBC surface normal

```
# global model parameters
Units = cm
Conformal = yes

# background material
Material(0) = vacuum

# input shapes
Shape(1) = lossy_pipe.stl
Material(1) = lossy_metal
Conductivity(1) = 0.58e+6
LossyOrder(1) = 10
```

Example input in PBCI

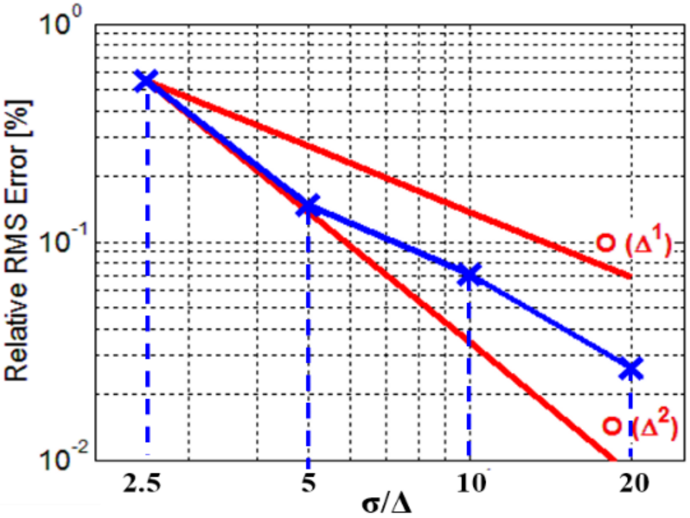
Surface impedance models

- Approximation of curved PEC boundaries

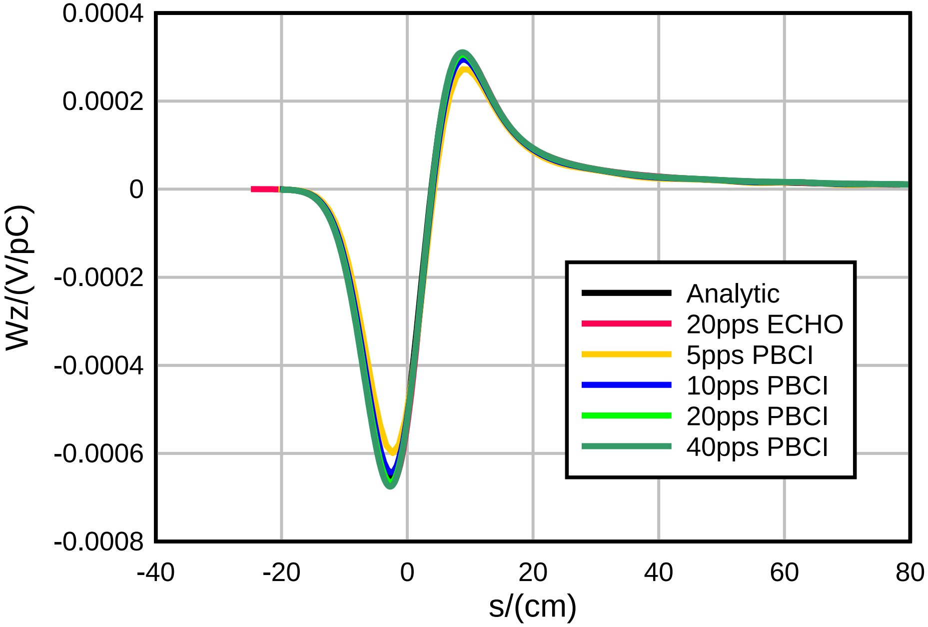


TiAl round pipe, L=60cm, R=6cm

Bunch: σ=5cm

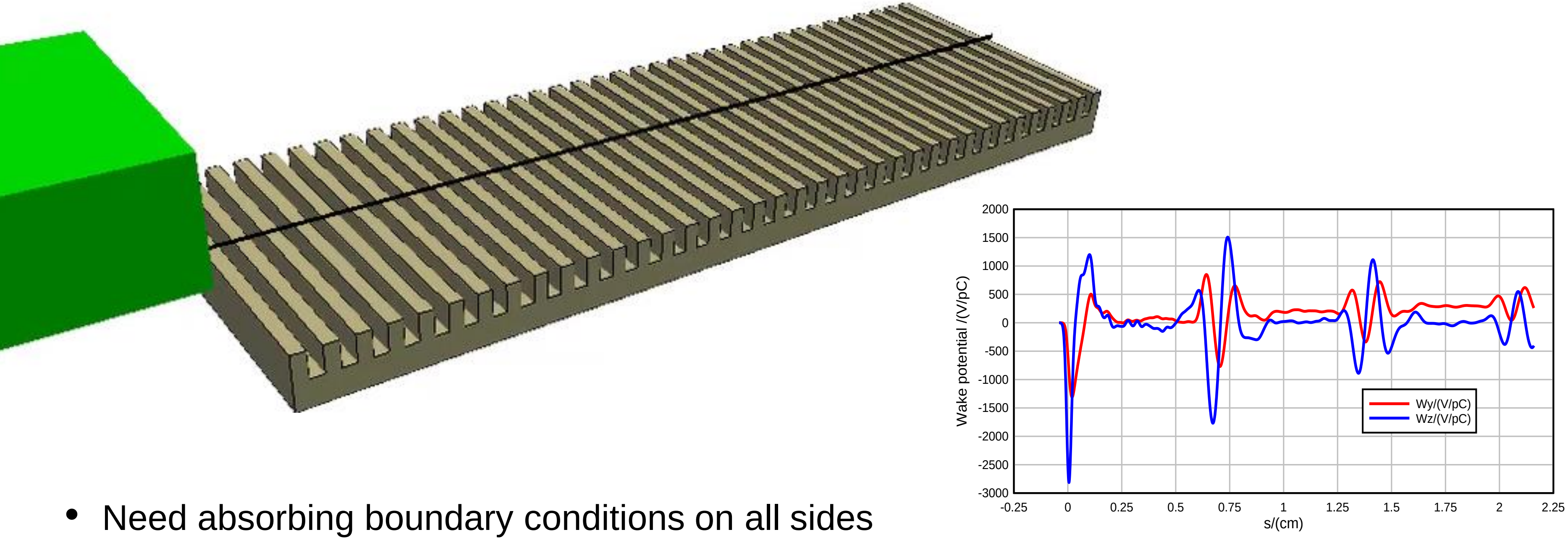


Comparison with ECHO2D and analytical solution



Absorbing boundaries for open structures

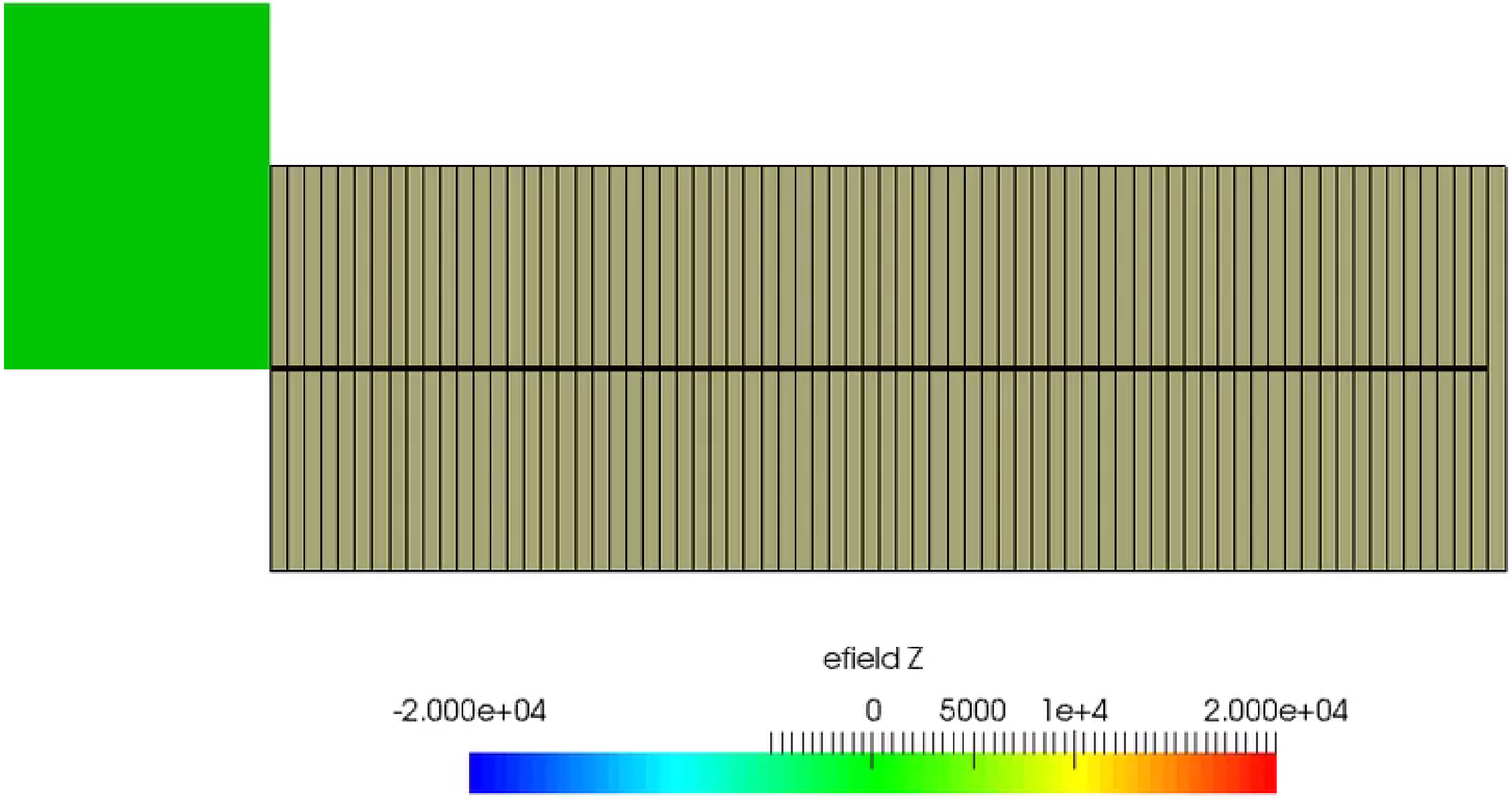
- Single plate dechirper (reloaded)



- Need absorbing boundary conditions on all sides
- Complex frequency shifted formulation of PML (CFS PML) now implemented in PBCI
- Absorbing layers of variable length and different conductivity are supported

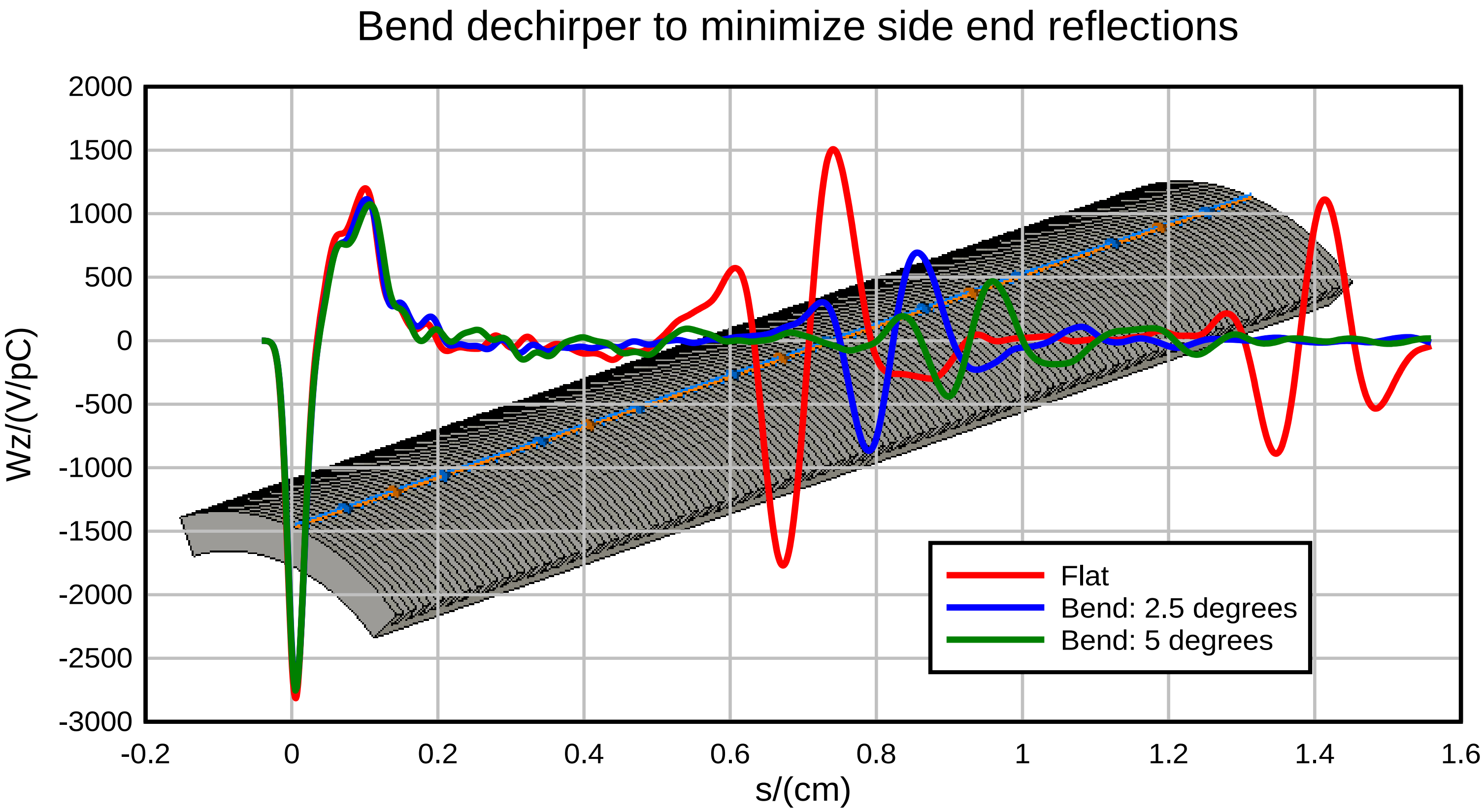
Open structures

- Single plate dechirper (reloaded)



Open structures

- Single plate dechirper (reloaded)



Summary

- Report of some activities in 2017
- New implementations in PBCI
  - Boundary conformal approximation (PEC only)
  - Dielectric materials
  - Surface impedance model
  - Open structures
- Not yet completed
  - Surface impedance from table data
  - Anisotropic SIBC, calculation of total wall losses, …
  - User parameter control for PML