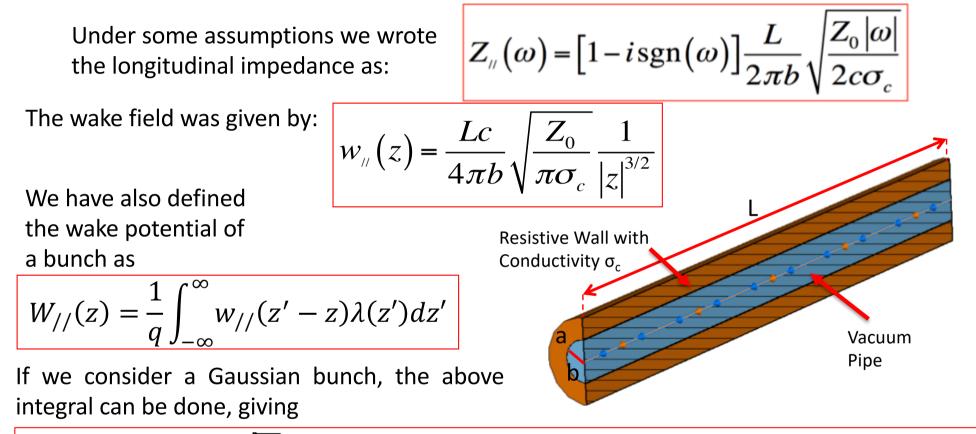


Let's review the theory:



$$W_{//}(z) = \frac{cL}{4\pi b\sigma_z^{3/2}} \sqrt{\frac{Z_0}{\sigma_c}} |x|^{3/2} e^{-x^2} \{ I_{-3/4}(x^2) - I_{1/4}(x^2) + \operatorname{sgn}(z) [I_{3/4}(x^2) - I_{-1/4}(x^2)] \}$$

with $x = z/2\sigma_z$

WHY CST?

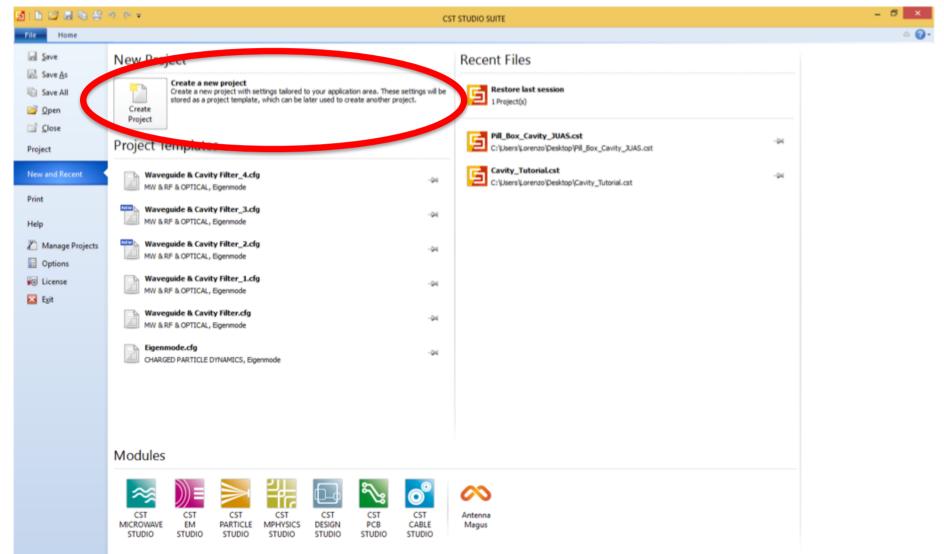
CST Studio Suite is a software used for the study of electromagnetic fields. It comprises tools for the design and optimization of accelerator devices operating in a wide range of frequencies, from static to optical. Analysis may also include thermal and mechanical effects, as well as circuit simulations.

WHAT ARE WE GOING TO DO?

In this tutorial we are going to show, step by step, how to use CST in order to design a <u>resistive wall pipe</u> and determine wake potential and impedance.

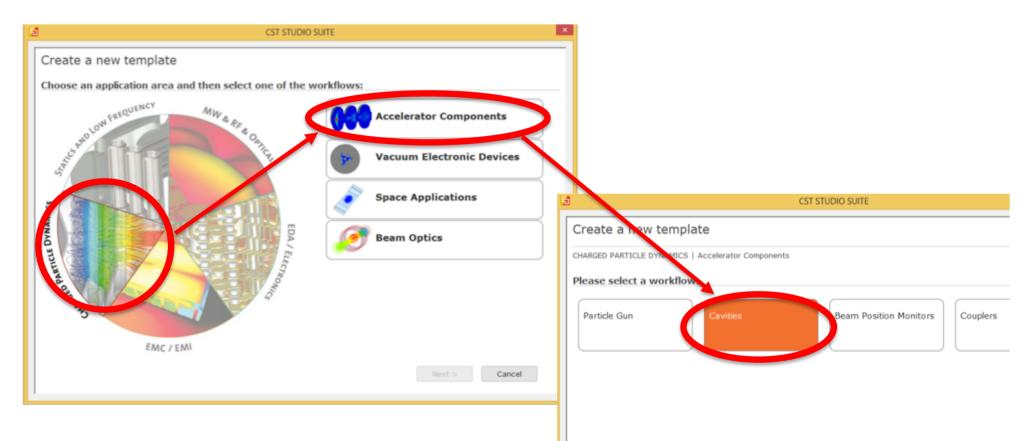
READY TO GO!

Open CST studio suite and select "Create a new Project"



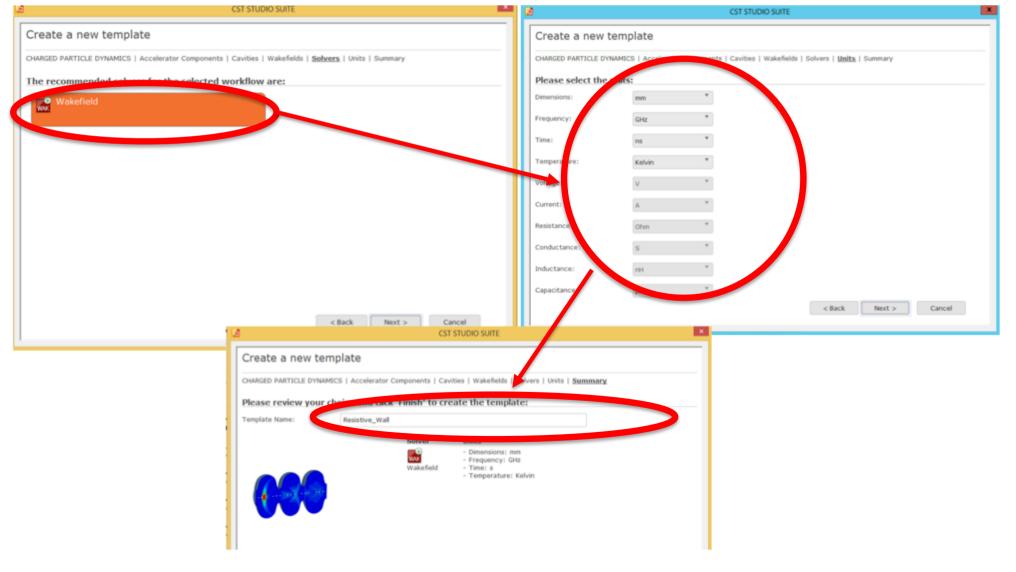
READY TO GO!

Now we need to select the correct Solver, Wakefield. Thus let's select Charged Particle Dynamics-> Accelerator Components -> Cavities



READY TO GO!

Then "Wakefield". After that, we select the working dimensional units (mm, GHz, s,...) and call the file as : Resistive_Wall



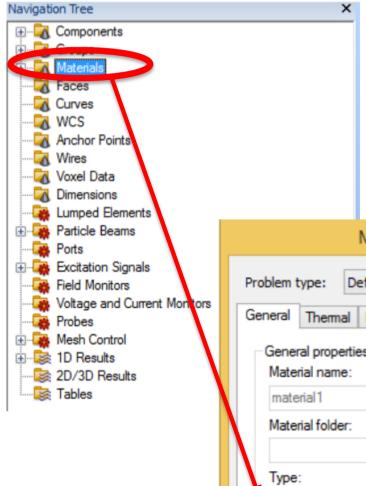
READY TO GO!

You should now see a screen like this one.

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ile Home Modeling Simu	lation Post P	Processing	View								۵ ۵
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	Parameter						-	×	lessages		
	V Name	/ parameter>	Expression	1	Value	Description	Туре				
	Paramete	r List 🗍 Res	sult Navigator						Messages Pro	gress	

The working window is divided into 5 sub-windows (but it depends on the chosen preferences). The largest one shows the figure of the device you are designing.

MODELING

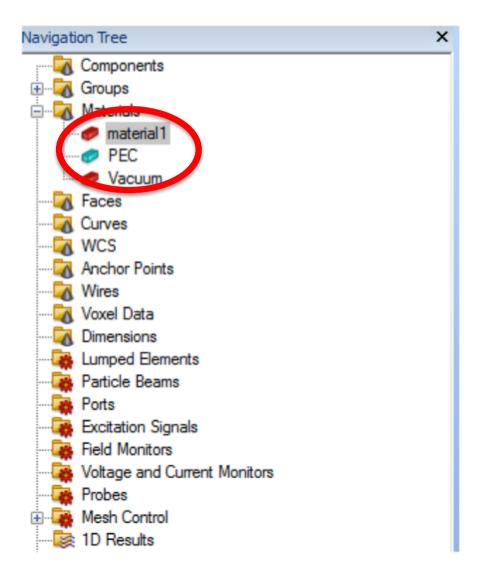


Let's now define a new material with a given conductivity. Let's select "materials" on the navigation tree on the left of the working window. Then, right-click on the folder and select "New Material..." from the menu. Select "Lossy metal" as "Type" in the General menu and then set the conductivity value at 3e3 S/m.

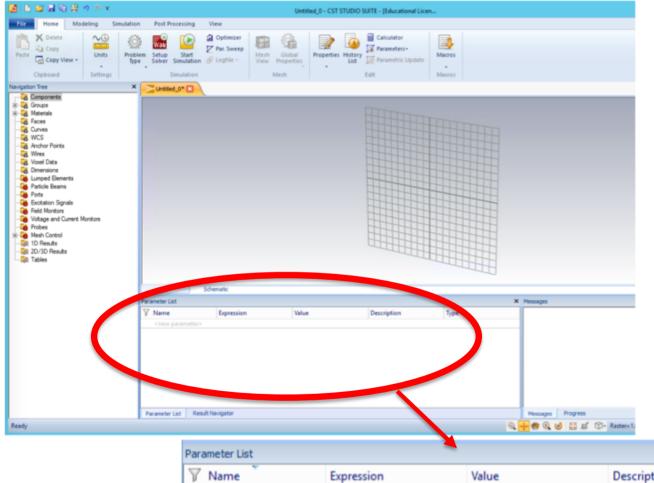
		Material Parameters: material
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Mate mat Mate Type Los PEC Non Anis Los	Themal Mechanics Density eral properties erial name: erial 1 erial folder: e: ssy metal Coating	General Themal Mechanics Density General properties Material name: material 1 Material folder: ✓ Type: Lossy metal ✓ Plectric conductivity: Mue: 3e3 S/m Color 0% O% Transpa

Simulation of a Resistive Wall Pipe MODELING

Now you should be able to see your new material in the materials list as shown.



MODELING



let's introduce the now geometrical dimensions of the beam pipe as parameters. This will allow easily to modify the entire model in future. It is possible to enter the parameter name, its expression (it could be a value, according dimensional the units to previously selected, or a combination of other parameters), its description and its type.

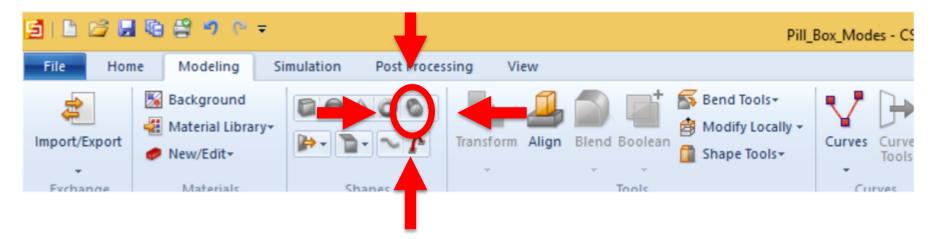
Parameter List					×
🝸 Name 🌷	Expression	Value	Description	Туре	
L	= 150	150		Length	~
a	= 12	12		Length	~
b	= 10	10		Length	~
<new parar<="" td=""><td>meter></td><td></td><td></td><td></td><td></td></new>	meter>				
Parameter List	Result Navigator				

MODELING

Now click on "Modeling" item on the top menu



Then select the cylinder



MODELING

Press esc. You should visualize the following window.

Cylinder	
Orientation OX OY OZ	Cylinder
Outer radius: Inner radius: 0 0.0 Xcenter: Ycenter: 0 0 Zmin: Zmax: 0 0 Segments: 0 0 0 Segment1 Material: Help	Name: OK Vacuum_Pipe Cancel Orientation OX OY OZ Preview Outer radius: Inner radius: b 0.0 Xcenter: O.0 Xcenter: O O O Zmin: Zmax: -L L Segments: 0
Fill the windows as shown	Component:
and press OK. <u>Remember to</u>	component1 V Material:
select "Vacuum" as material.	Vacuum Help
You have now the vacuum pipe.	

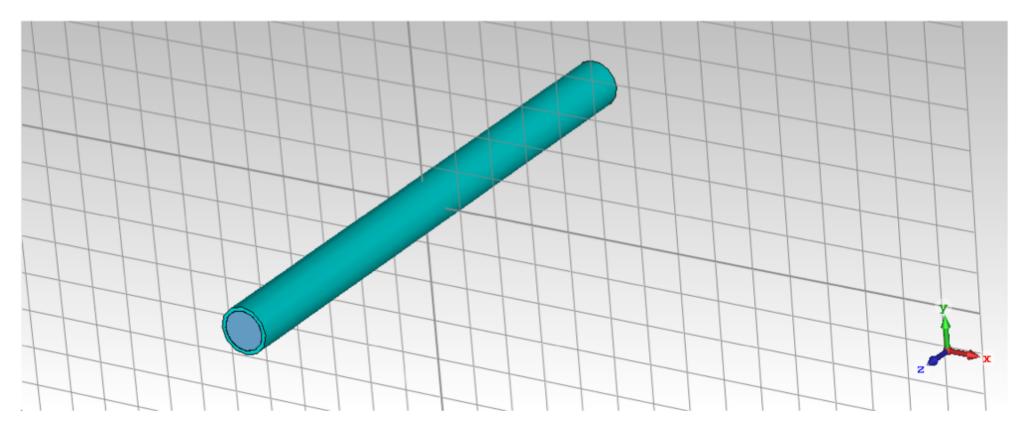
MODELING

Repeat the instructions to create a resistive beam pipe, filling the window as shown below

Cylinder				
Name: OK rolid1 Cancel Orientation ○ X ○ Y ● Z Cancel				
Outer radius: Inner radius:			Cylinder	
0 0.0 Xcenter: Ycenter: 0 0 Zmin: Zmax: 0 0 Segments: 0 0 0 Segment1 ✓ Material: ✓ Vacuum ✓ Help ////////////////////////////////////		Name: Resistive_Wall Orientation OX Outer radius: a Xcenter: 0 Zmin:	OY ●Z Inner radius: b Ycenter: 0 Zmax:	OK Cancel Preview
3D Schematic		-L	L	
		Segments:		
Fill the windows as shown		Component:		
and press OK. <u>Remember</u>	<u>to</u>	component1	~	
<u>select "material1" as mate</u>	erial.	Material		
Here it is the resistive pipe		material 1	~	Help

MODELING

This is our Resistive Beam Pipe!



The geometry is done!

ANALYSIS

We are almost ready for simulations, but we first need to define the particle beam, that is the source of the wakefield.

x

Define Particle Beam

Let's right-click on "Particle Beams" in the "Navigation Tree" window and select "New

Particle Beam". Then set the values as shown.

Navigation Tree X	Name: OK
	ParticleBeam1 Cancel
Groups Groups Materials Groups Curves WCS Anchor Points Wires	Beam properties Shape: gaussian ✓ Preview Wakefields Velocity (beta): 1.0 Charge: 1e-9 C
Voxel Data Dimensions Umped Elements Particle Beams	Gaussian beam Sigma: 15
Excitation Signals Field Monitors Voltage and Current Monitors Probes Mesh Control ID Results	Current in the here: Transmission line ✓ Mesh settings ✓ Consider for mesh refinement Lines per sigma: 10.0

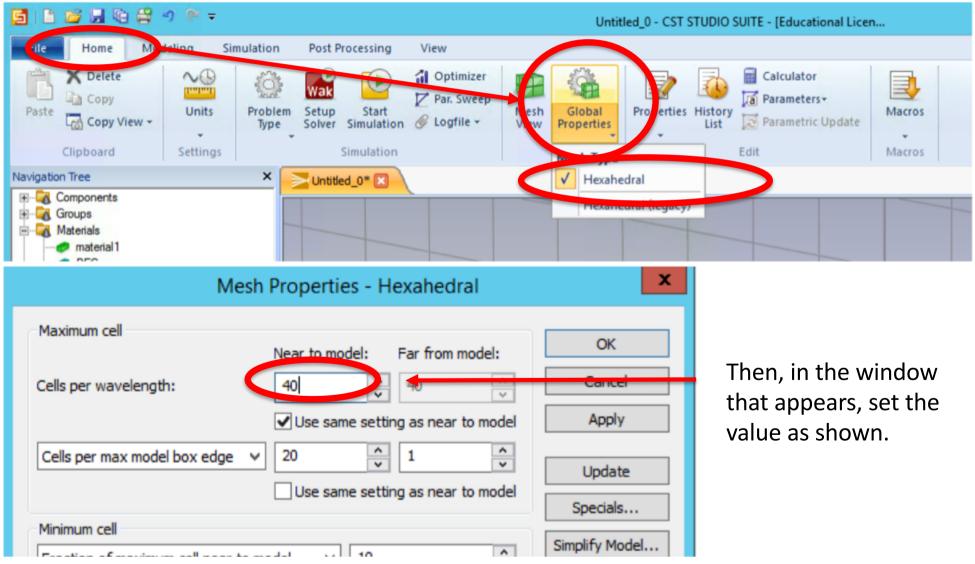
ANALYSIS

Click now on "Wakefields..." and change the "Wake integration method" from "Direct" to "Indirect testbeams" (if possible, you should always use it). In addition to that, let's apply a roll-off parameter of 0.5 (this will lead to a smoother solution, removing numerical noise in the results).

Define Particle Beam	x	_		
Name:	ОК		Wakefield calculati	on ×
ParticleBeam1	Cancel		Wake integration method	ОК
Beam properties	Preview		Indirect testbeams	Cancel
Shape: gaussian V	Wakefields		Integration path shift	Help
Velocity (beta): 1.0	Help		X-shift: 0.0	
Charge: 1e-9 C	hep			
			Y-shift: 0.0	
Gaussian beam			Z-shift: 0.0	
Sigma: 15			Wake impedance spectrum	
Current injection scheme: Transmission line 🗸			Apply cos ² filtering	
Mesh settings			Roll-off factor: 0.5	
✓ Consider for mesh refinement				
Lines per sigma: 10.0				

ANALYSIS

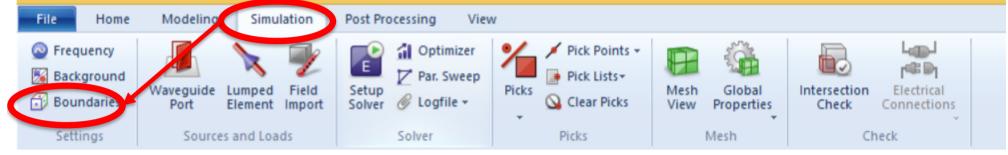
Let's now adjust the mesh. Select, from the top menu, Home -> Global Properties -> Hexahedral



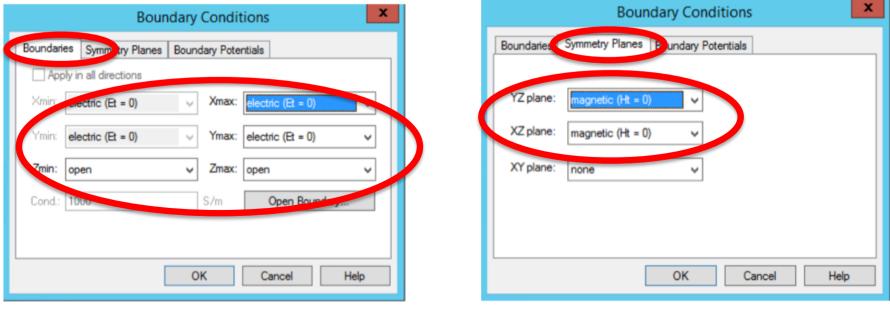
ANALYSIS

Almost done.

Click on "Simulations" on the top menu, then "Boundaries"

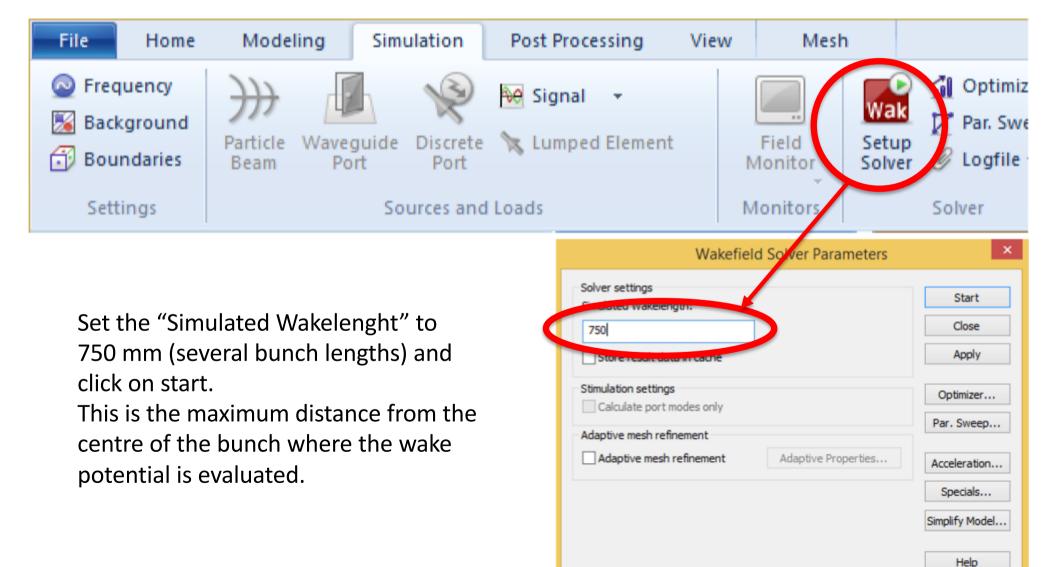


Let's now select the simmetry planes of our geometry from the "Symmetry Planes" window (YZ Ht=0 and XZ Ht=0) and the boundaries as shown below.



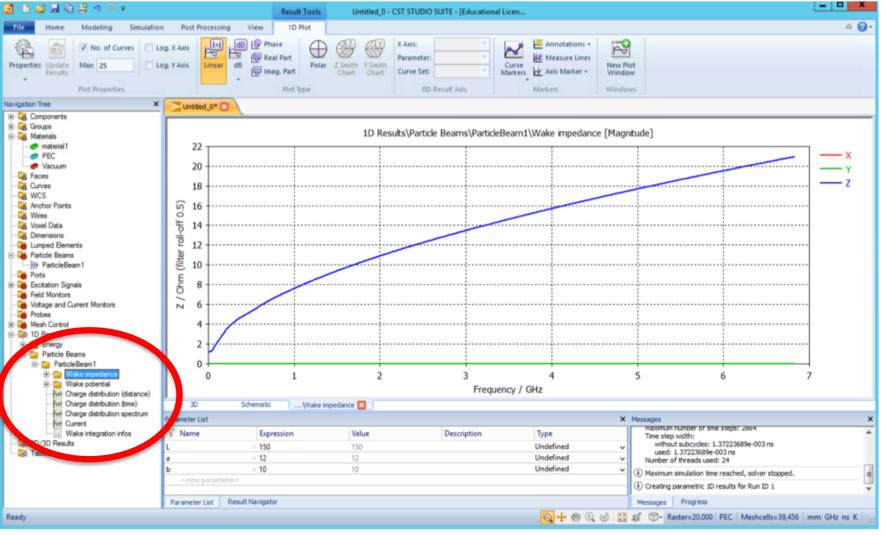
ANALYSIS

Now we are ready. From the Simulation bar click on "Setup Solver"



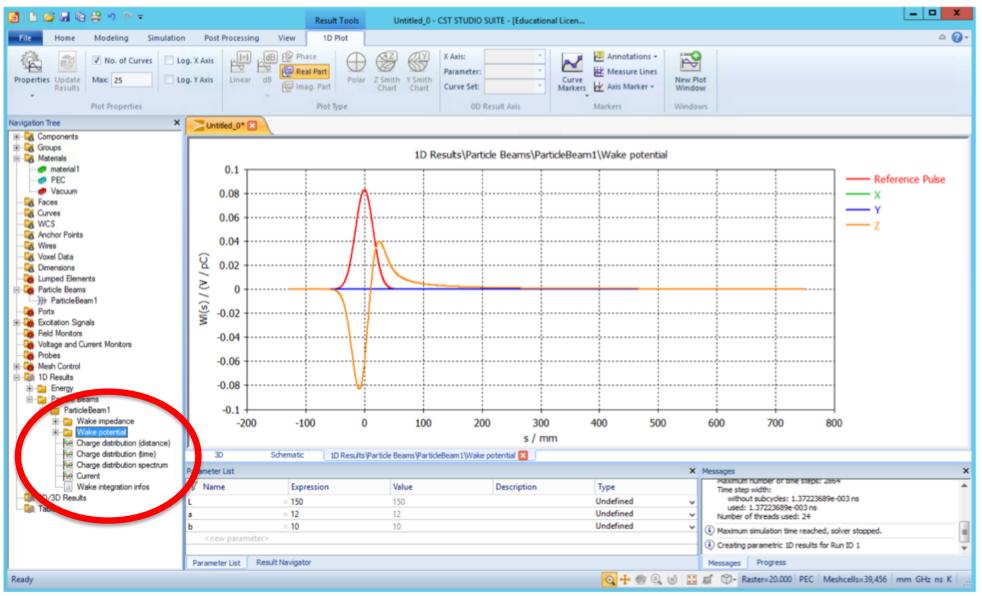
ANALYSIS

After a while we have our results on the navigation tree. Clicking on the folder 1D Results -> Particle Beams -> ParticleBeam1, we can plot the impedance and the wake potential. This is the impedance (absolute value).



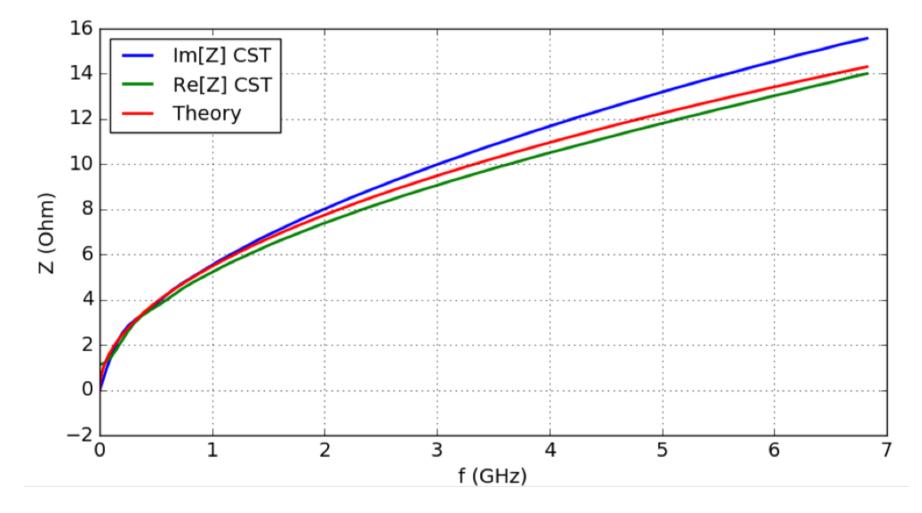
ANALYSIS

And this is the wake potential.



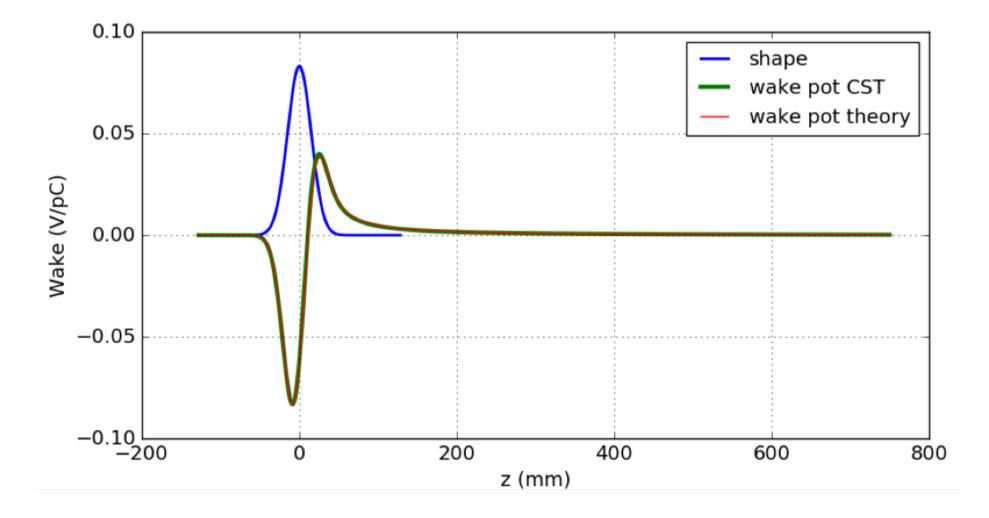
Comparison with theory

$$Z_{\prime\prime}(\omega) = \left[1 - i \operatorname{sgn}(\omega)\right] \frac{L}{2\pi b} \sqrt{\frac{Z_0 |\omega|}{2c\sigma_c}}$$



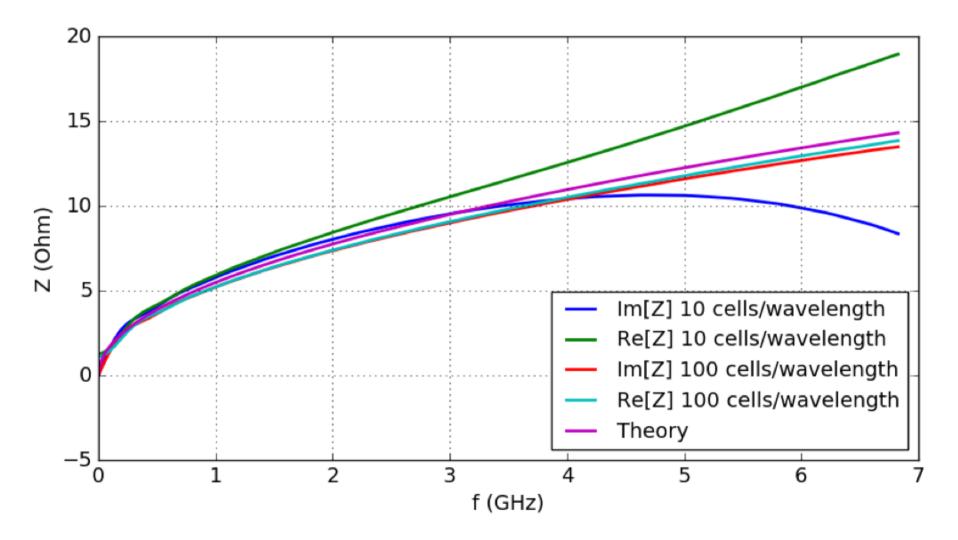
Comparison with theory

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LAST BUT NOT LEAST

CST, as other codes which use Finite Difference Method, is particularly sensitive to the mesh accuracy. In order to better understand this point, let's change the "cells per wavelenght" from 40 to 10 or 100 ...



LAST BUT NOT LEAST

Try a simulation with:

- 1) Load from material library: pure copper
- 2) Pipe in copper
- 3) Bunch length 25 mm
- 4) Cells per wavelength 10 ... 60
- 5) Simulated wavelength 3000 mm
- 6) Look at the real and imaginary part of the impedance