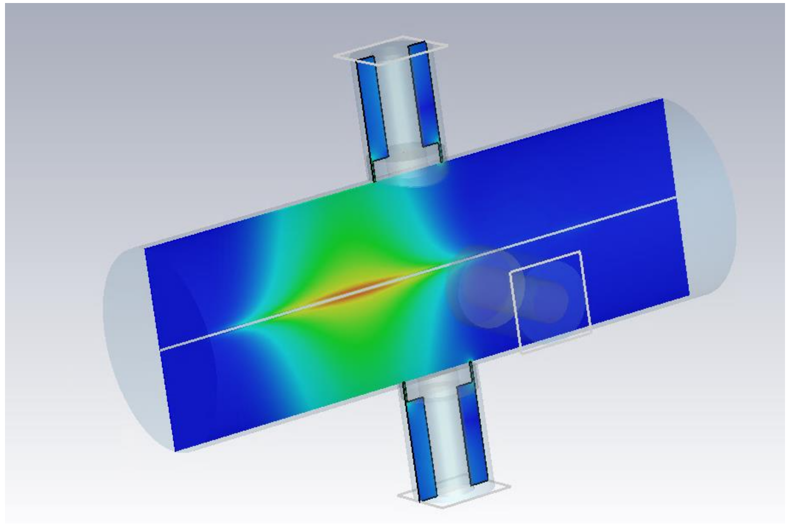
FEEDBACK ON BPM SIMULATIONS WITH CST STUDIO SUITE



DEELS 2024

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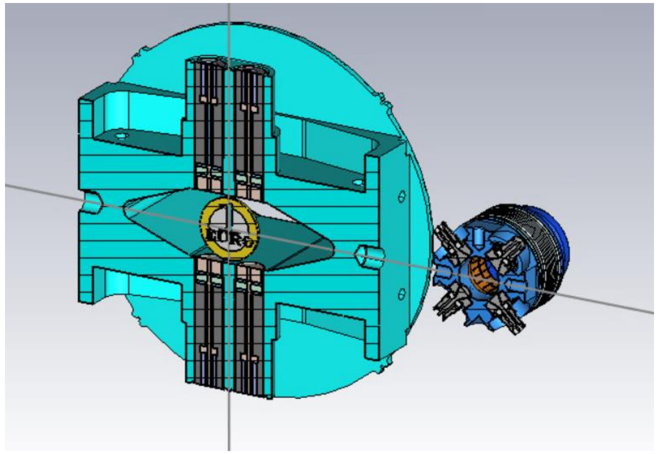
SOLEIL SYNCHROTRON

MOUSSA EL AJJOURI

OVERVIEW

- SIMULATION WORKFLOW
- THERMAL ANALYSIS
- CST CONFIGURATION
- MESH CONFIGURATION AND SIMULATION DURATION
- NON-VANISHING SIGNALS
- TRANSFER IMPEDANCE
- SIMULATION FOR THE LONGITUDINAL ASYMMETRIC MODELS
- SIMULATION DURATION FOR THE TRANSVERSAL ASYMMETRIC GEOMETRIES AND/OR LARGE STRUCTURE
- THE SIMULATION OF COATING RESISTIVITY
- EVALUATED HEAT FOR THE NON-GAUSSIAN BEAM DUE TO THE RF HARMONICS CAVITIES.

OBJECTIVE OF THIS WORK



EVALUATION OF HEAT DISSIPATION IN THE BPM BUTTONS

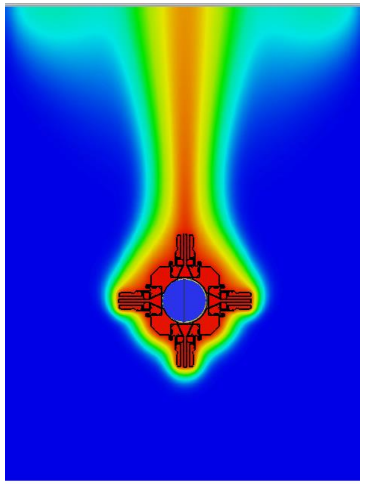
The power loss is given with the following formula [1,2]

Mbtrack2 [3,4]

$$\Delta P = (f_0 e N_{beam})^2 \sum_{p=-\infty}^{p=+\infty} |\Lambda(p\omega_0)|^2 Re\left[Z_{||}(p\omega_0)\right]$$

CST wakefeild solver [5]

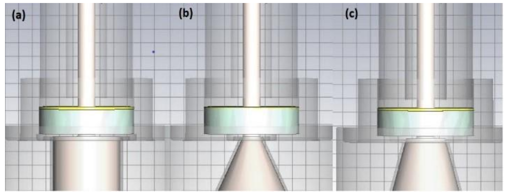
- The equation shows that the power loss is influenced by both the spectral content of the beam and the characteristics of the accelerator structure
- Understanding these relationships is crucial for designing and operating efficient particle accelerators, where minimizing power losses is essential for performance and stability of the measurements, and to prevent overheating and damage to the equipment.

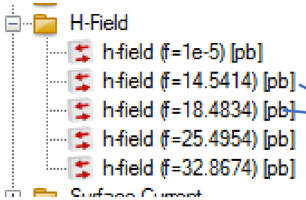


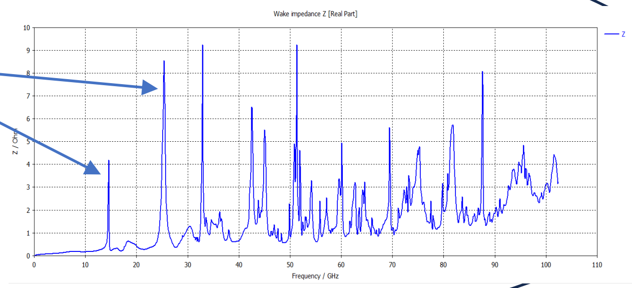
1. https://cds.cern.ch/record/2671644/files/thpak093.pdf
2. https://accelconf.web.cern.ch/ipac2018/papers/thpal059.pdf
3. https://accelconf.web.cern.ch/ipac2021/papers/mopab070.pdf
4. https://gitlab.synchrotron-soleil.fr/PA/collective-effects/mbtrack2
5. https://www.3ds.com/products/simulia/cst-studio-suite/electromagnetic-simulation-solvers#Brick-6be5401b-a2b4-41e3-b3e2-c130c91b8577

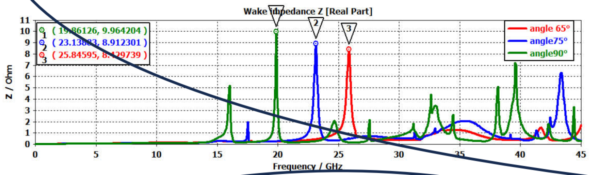
SIMULATION WORKFLOW

Optimize the real part of longitudinal impedance







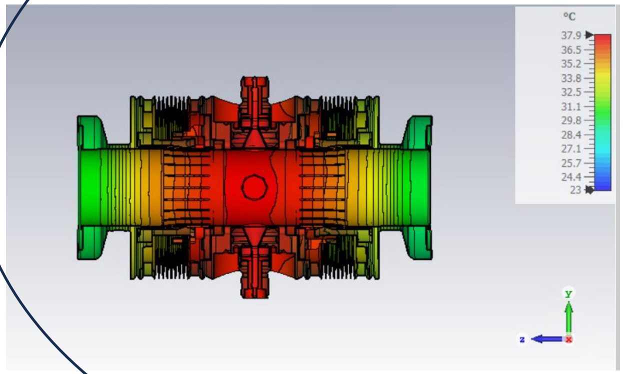


Wakefeild Solvers

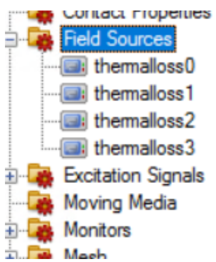
power loss calculation

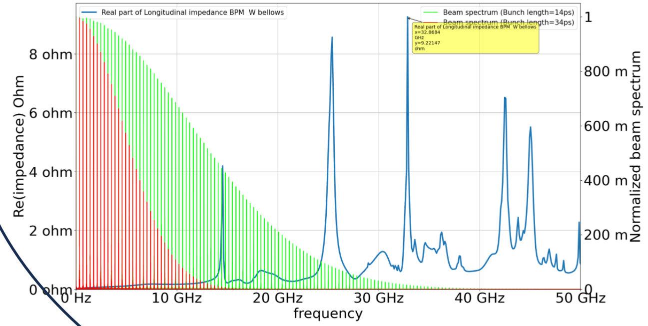
MBTRACK

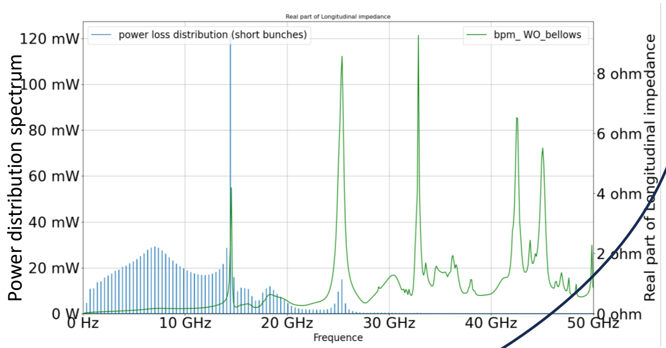
Thermal simulation



Thermal Solvers





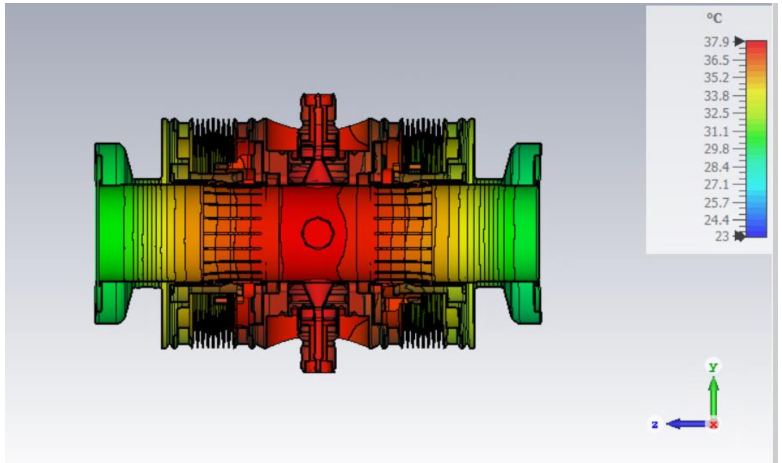


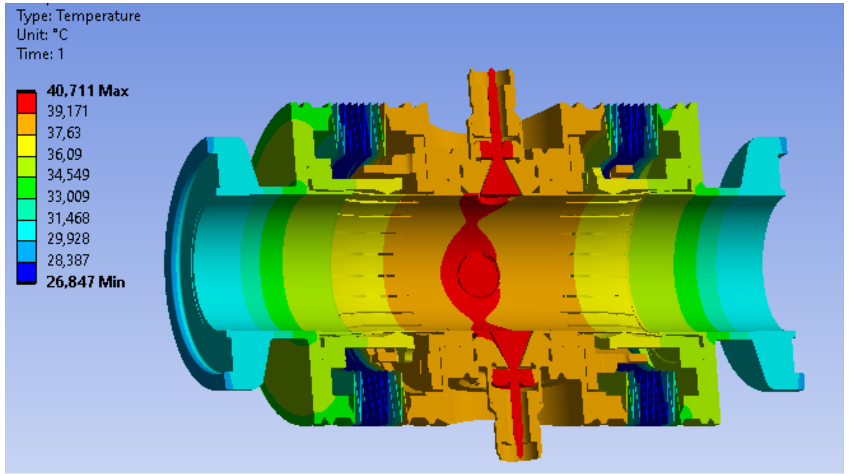
THERMAL ANALYSIS

THs

Ansys

Thermal Analysis Software





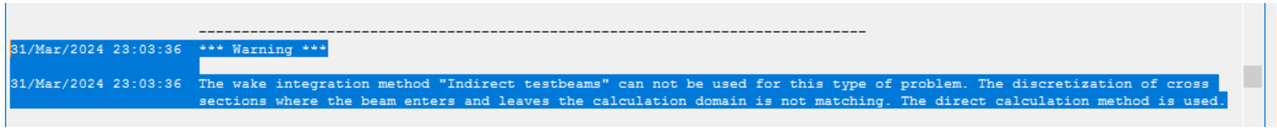
By courtesy of FAN Zhengxuan

A cross-validation with another dedicated software and by a thermal simulation expert is necessary

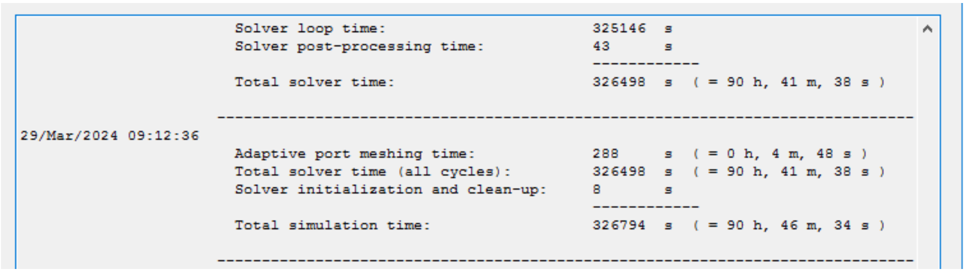
CST CONFIGURATION

The CST software is a user-friendly, but there are many parameters to configure depending on your model and the solvers you use. It is important to pay attention to all the configuration menus and sub-menus, otherwise you run the risk of getting false results.

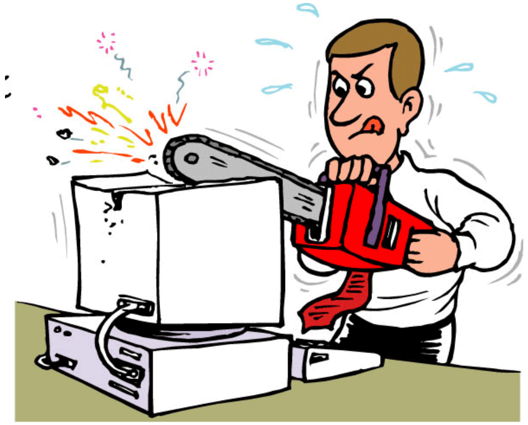
CST can continue the simulation without error or simply with a warning in the log file.

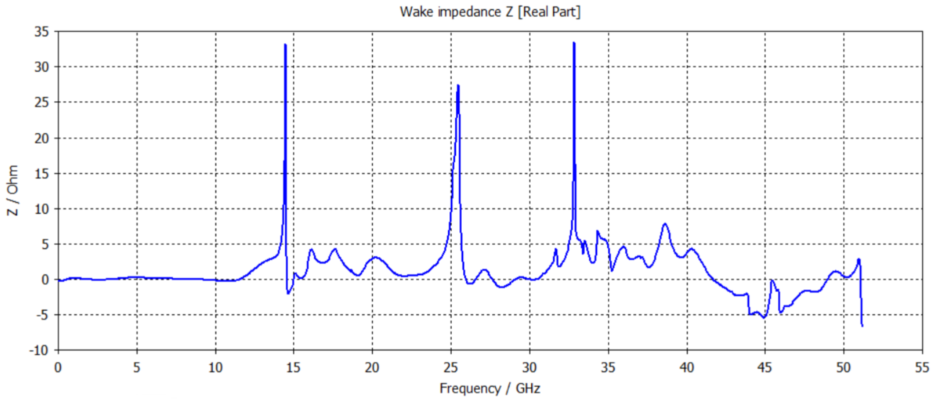


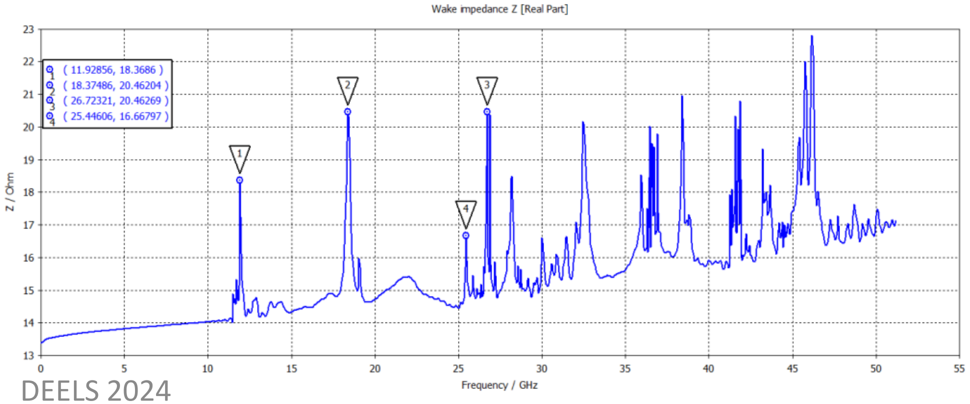
```
31/Mar/2024 23:03:36  *** Warning ***

31/Mar/2024 23:03:36  The wake integration method "Indirect testbeams" can not be used for this type of problem. The discretization of cross
                      sections where the beam enters and leaves the calculation domain is not matching. The direct calculation method is used.
```



```
                     Solver loop time:                          325146  s
                     Solver post-processing time:               43      s
                                                                ------------
                     Total solver time:                         326498  s  ( = 90 h, 41 m, 38 s )
----------------------------------------------------------------------------------------------
29/Mar/2024 09:12:36
                     Adaptive port meshing time:                288     s  ( = 0 h, 4 m, 48 s )
                     Total solver time (all cycles):            326498  s  ( = 90 h, 41 m, 38 s )
                     Solver initialization and clean-up:        8       s
                                                                ------------
                     Total simulation time:                     326794  s  ( = 90 h, 46 m, 34 s )
----------------------------------------------------------------------------------------------
```

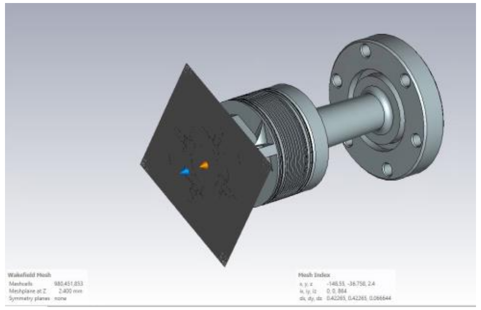




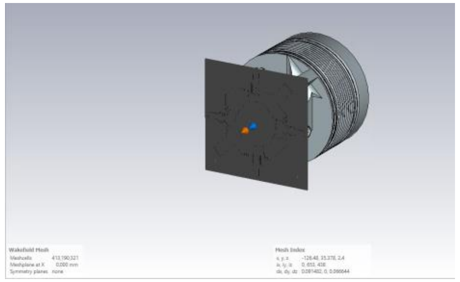


MESH CONFIGURATION AND SIMULATION DURATION

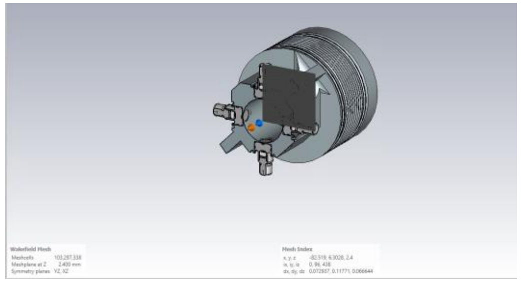
- Each mesh cell represents a small volume in space where the electric and magnetic fields are computed.
- It is important to use a mesh that is well balanced and offers a good compromise between simulation speed and accuracy
- When importing a mechanical model, it is important to delete all the parts which have no influence on the simulation (support, screws, flanges, etc.)
- Symmetrizing model permits to divide mesh number by two or four following the possible symmetry plans



Complete model: 1G meshes



Simplified model: 400M meshes



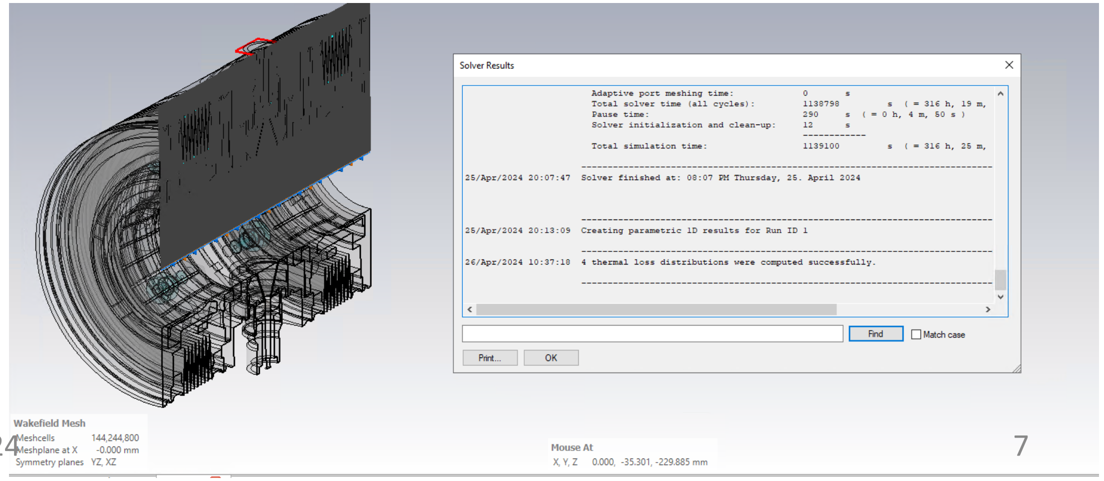
Symmetric model: 103M meshes

Simulation duration For 144M meshes : 316h

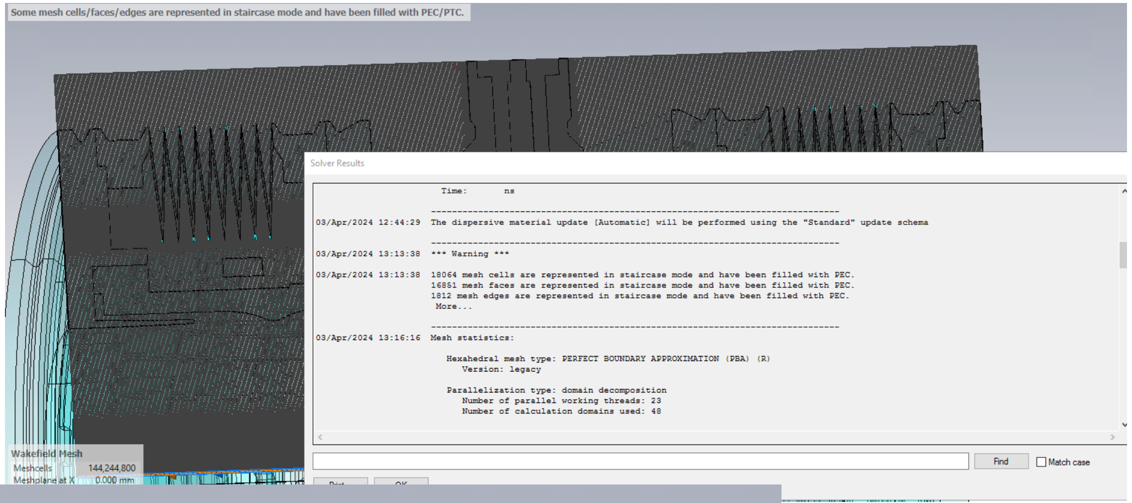
HARDWERE CONFIGURATION:

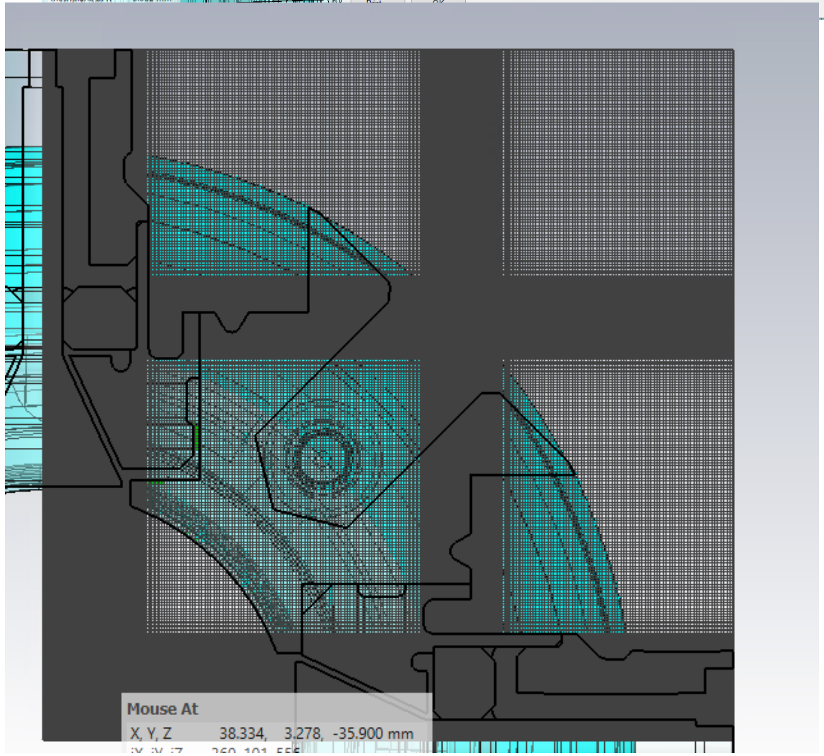
PROCESSOR :16 core Processor 3,2GHz(2 processors)

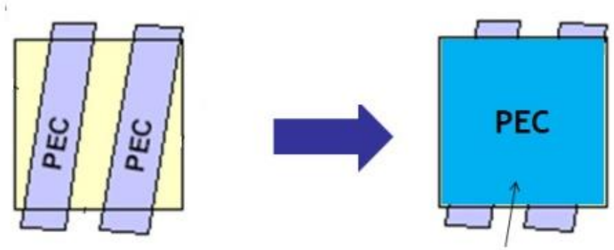
RAM: 384 GB



MESH ERROR





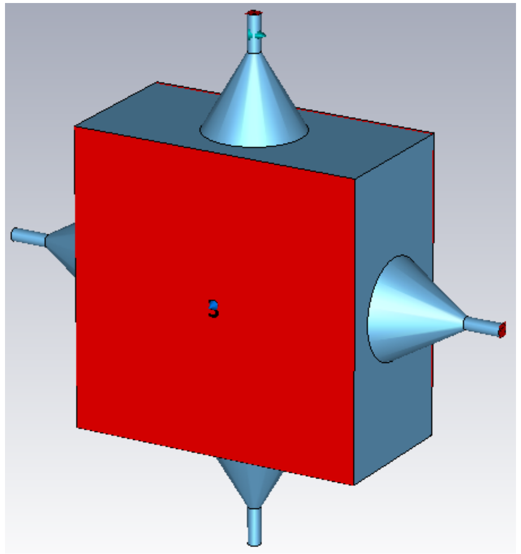


- Undetermined in the gap between the metallic objects
- The entire mesh cell is represented in staircase mode and filled with Perfect Electric Conductor (PEC) material
- Staircase cells can potentially create unwanted short circuits in the model.
- The formation of staircase cells can be controlled by refining the mesh, especially around the regions where small metallic gaps are present.

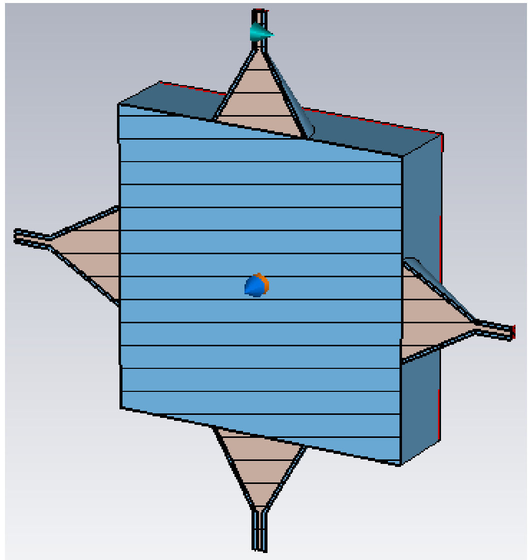
https://www.researchgate.net/file.PostFileLoader.html?id=578c450ceeae3937441b63a1&assetKey=AS%3A385033333428224%401468810508239

NON-VANISHING SIGNALS

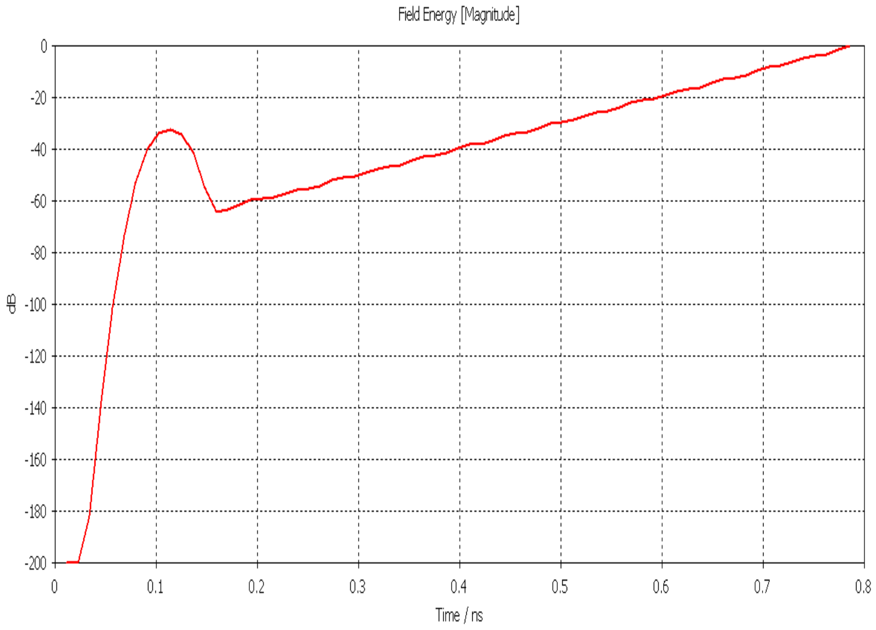
- energy in the structure increases over time ???



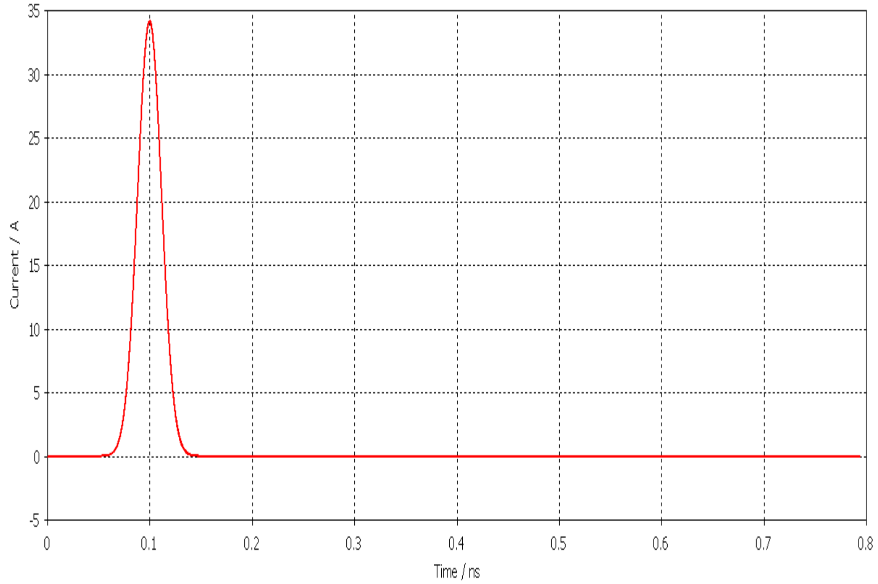
EM model



EM model cross section

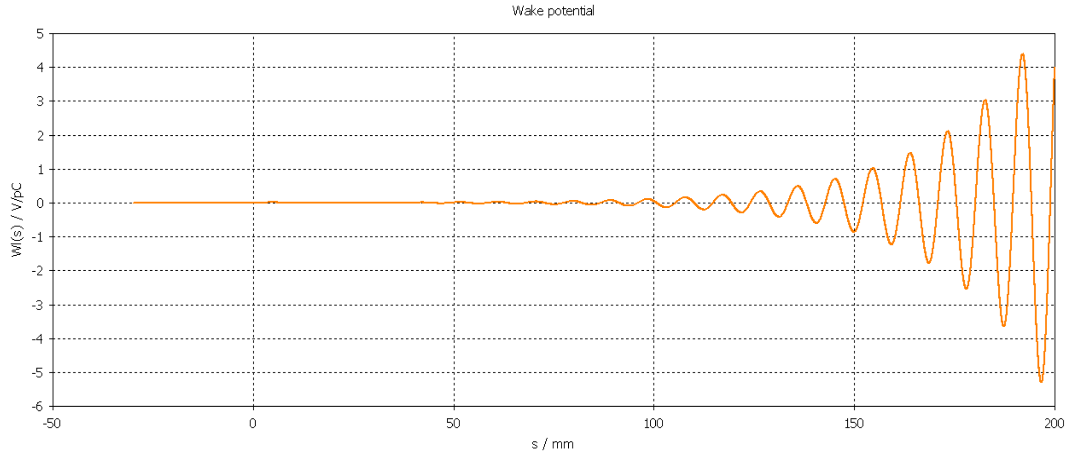


energy

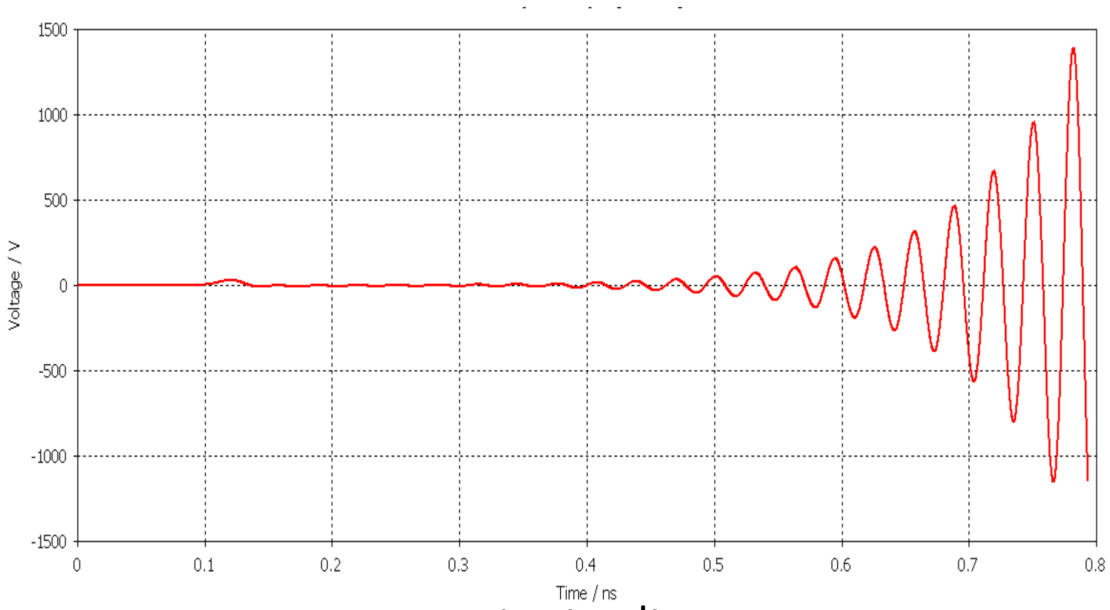


beam current

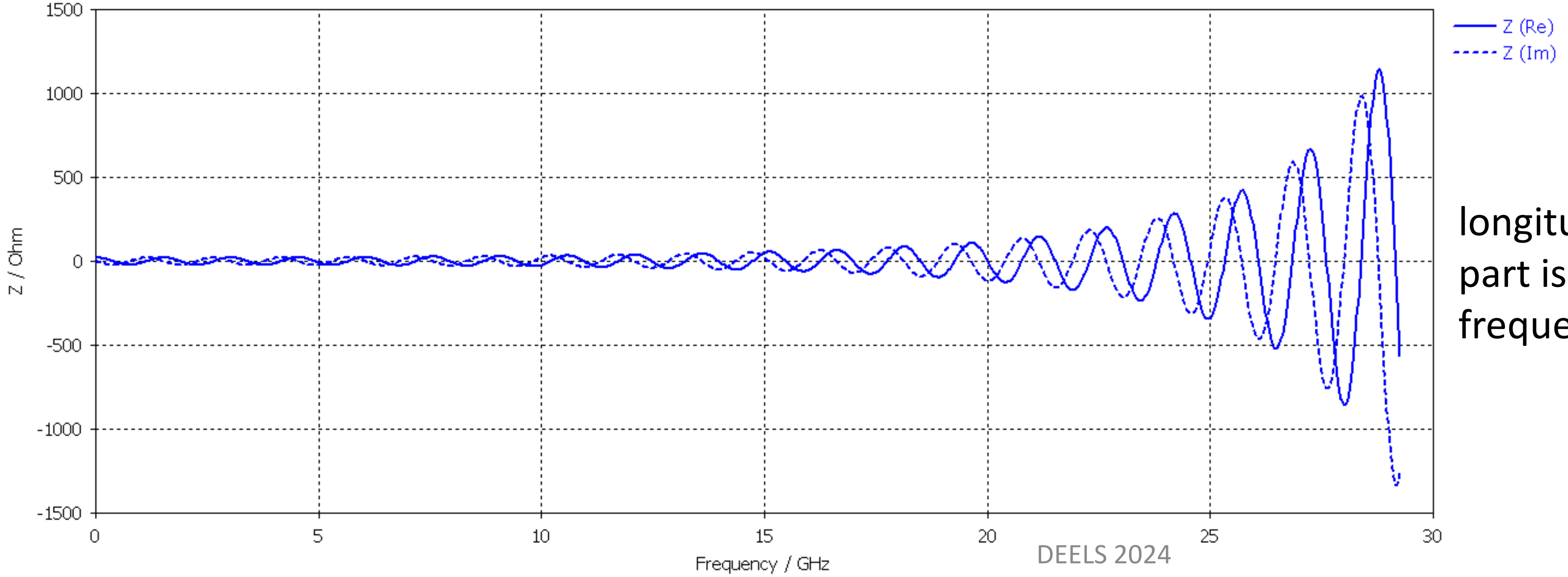
NON-VANISHING SIGNALS



longitudinal wake potential



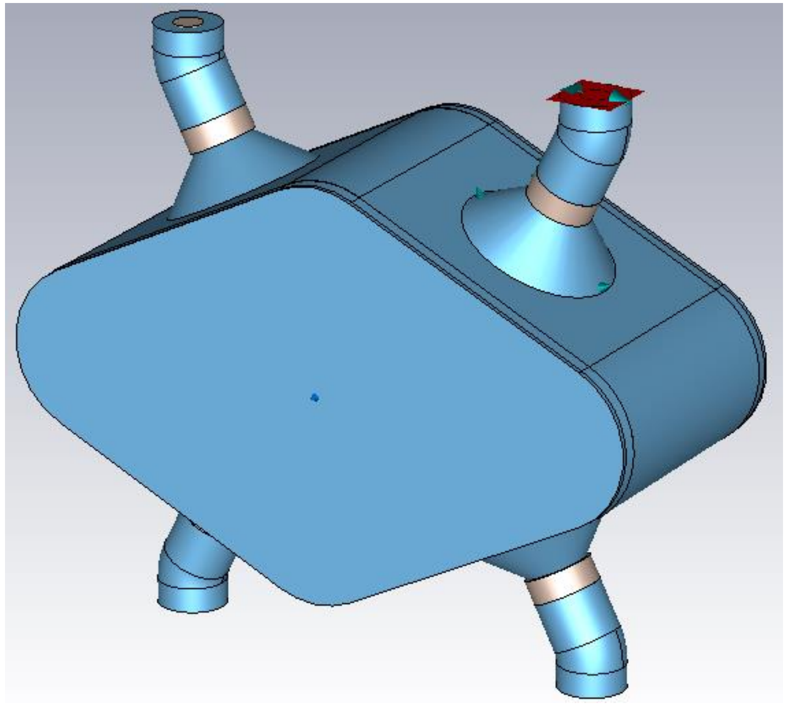
output voltage



longitudinal wake impedance: its real part is negative is some regions of the frequency spectrum ???

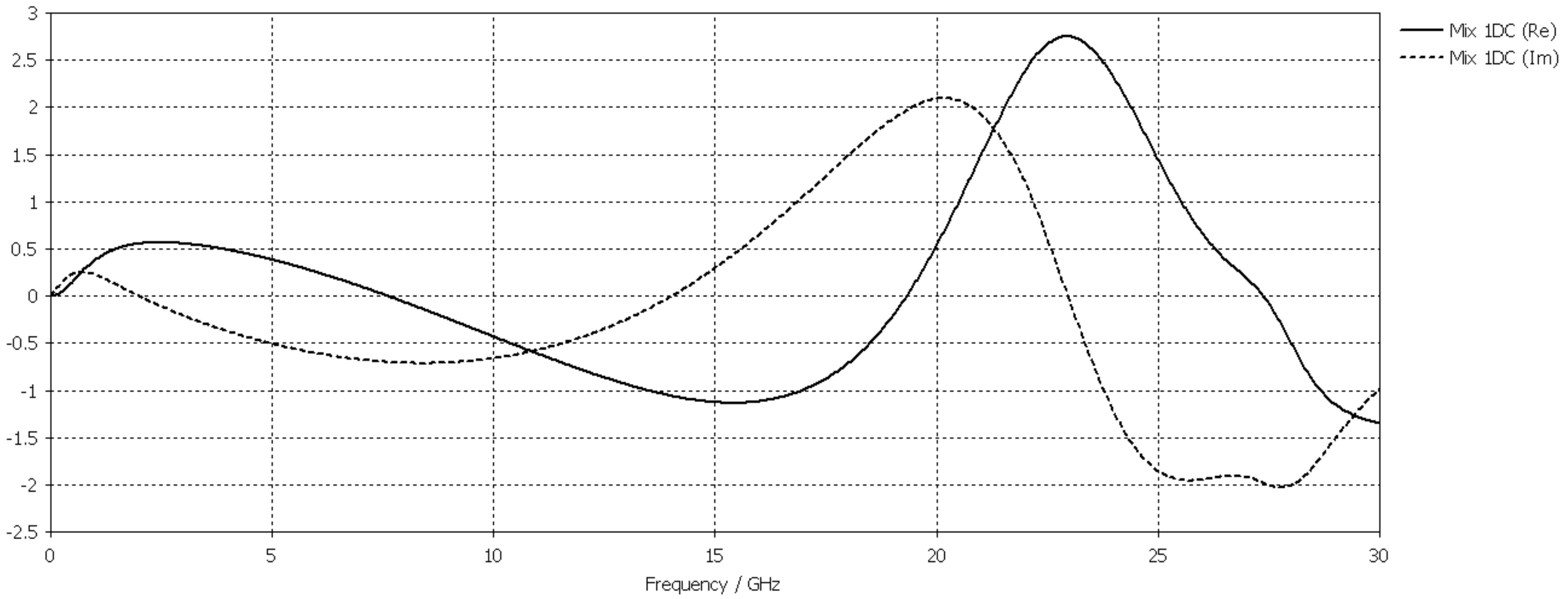
TRANSFER IMPEDANCE

- Real part negative in some regions of the frequency spectrum ???



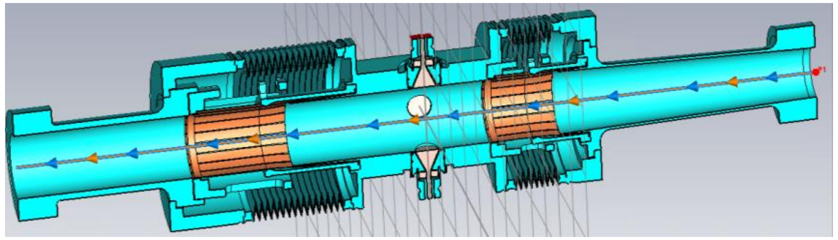
EM model

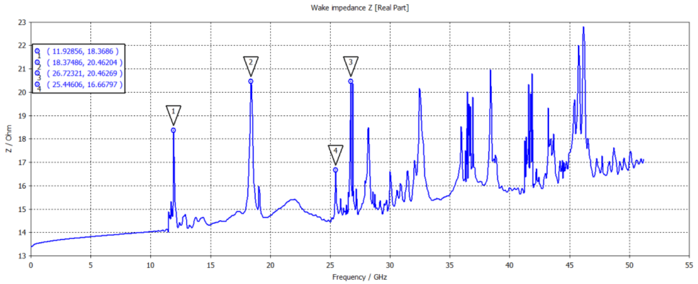
$$Z_T = V_{port}(f)/I_{beam}(f)$$

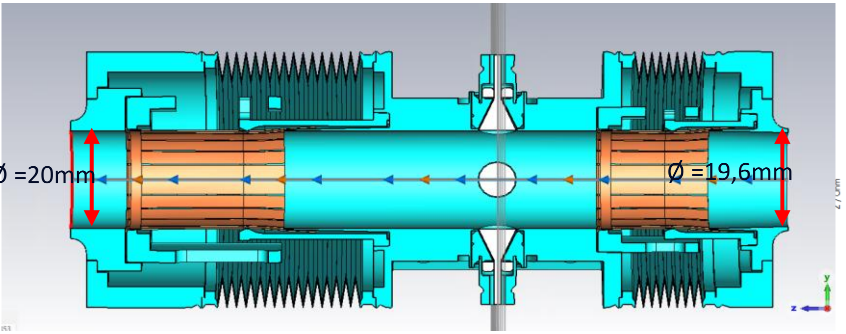


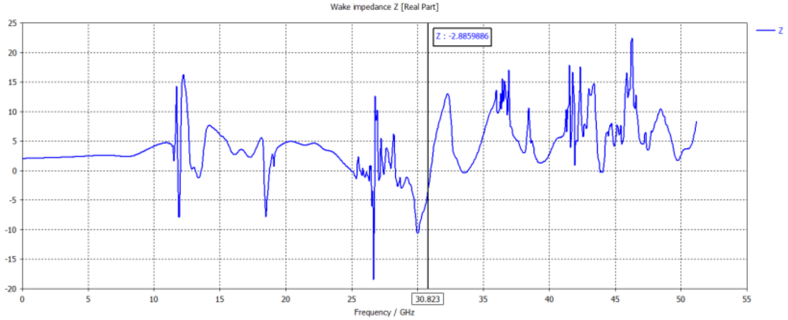
transfer impedance

SIMULATION FOR THE LONGITUDINAL ASYMMETRIC MODELS









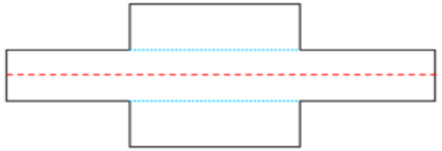
Direct

The direct method is the most general method but also less accurate than the two indirect methods. It is used if the particle beam is not ultrarelativistic, or if an indirect method is not applicable.

The wake potential is computed by an integration along an axis parallel to the beam axis.

Indirect testbeams

This is the most accurate integration method. It can be used if the beam has an ultrarelativistic velocity and the beam tubes cross section at the entry boundary equals the cross section at the exit boundary. In addition the structure must not be concave which means basically that the cross section of the part between the beam tubes must be larger than the tubes cross section. As a consequence a collimator cannot be treated with this integration method in general. The method is described more detailed in [2].



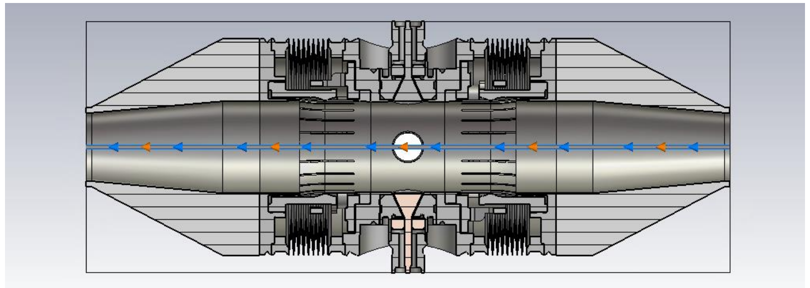
Indirect interfaces

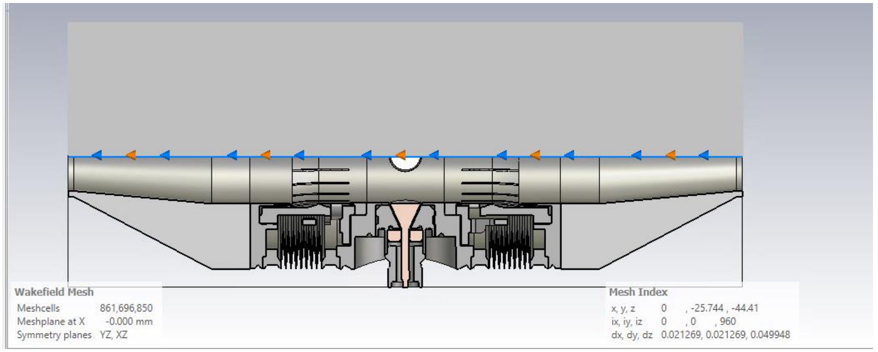
If the cross section of the beam tube varies at the entry and the exit boundary, one can choose this method for ultrarelativistic beams. The method is described more detailed in [3].

Component with different diameters at the entrance and the exit. Calculating the Wakefield is very difficult when the beam changes its propagation diameter, leading to inconsistent results.

CST propose different method following your geometry but switch automatically to default method "direct integration method". If geometry problems

SIMULATION DURATION FOR THE TRANSVERSAL ASYMMETRIC GEOMETRIES AND/OR LARGE STRUCTURE

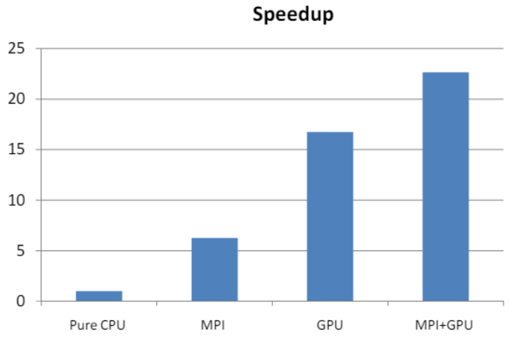




It is necessary to take into consideration the cost of hardware and licensing options which are not included in the basic license.

PCB and Package- 100M cells

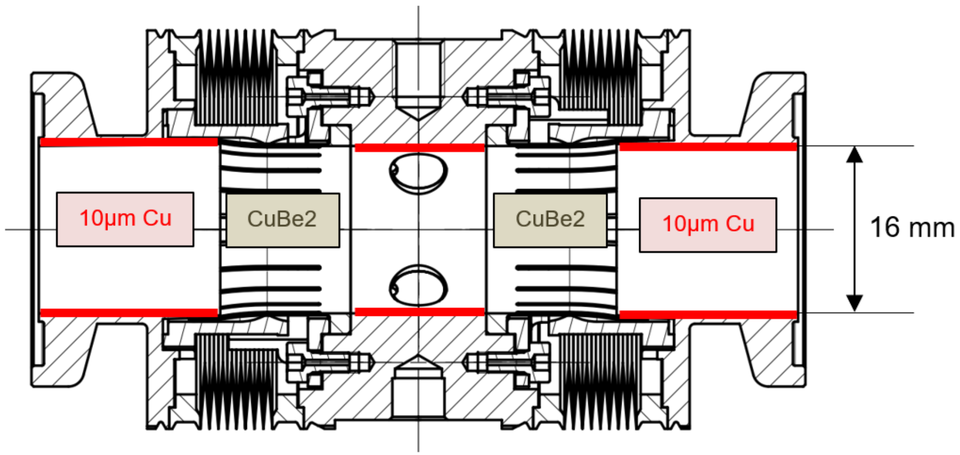
Test Case	# Nodes	# Cores per Node	# GPUs per Node	Total # GPUs
Pure CPU	1	2x4	0	0
MPI	8	2x4	0	0
GPU	1	2x4	4	4
MPI+GPU	4	2x4	2	8

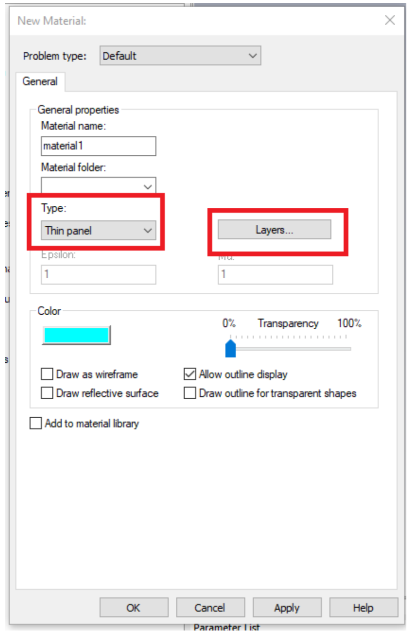


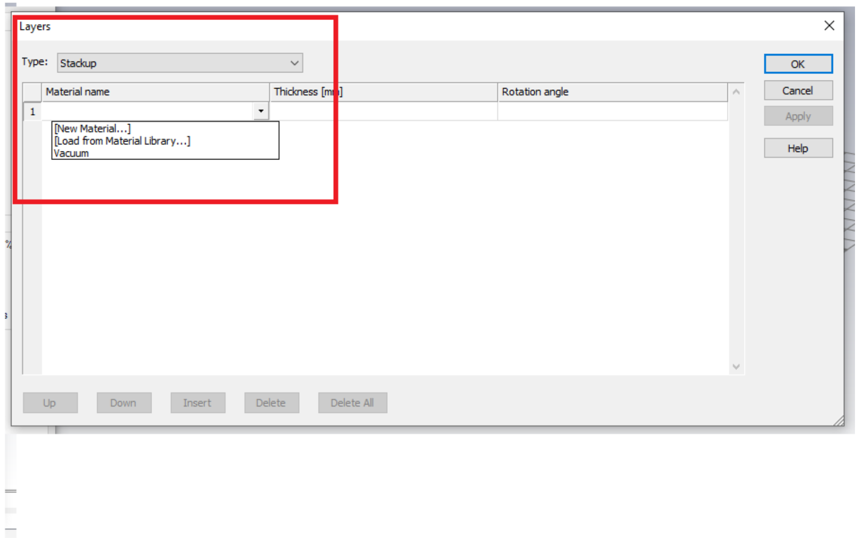
CST

https://www.nvidia.com/content/gtc-2010/pdfs/2133_gtc2010.pdf
https://www.3ds.com/support/hardware-and-software/simulia-systems-information/cst-studio-suite-opera-recommended-hardware

THE SIMULATION OF COATING RESISTIVITY



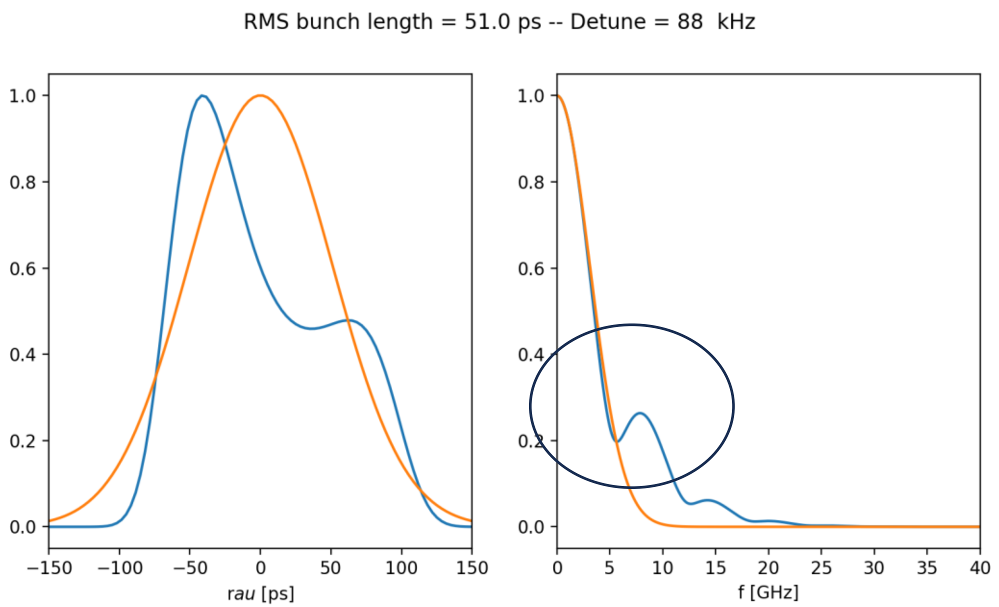




I suggest using the thin panel if this is possible in your model. The idea of the thin panel is that you will make a 2D sheet or something similar. In this panel you could put many small layers without having to make very small meshes, which would make the simulation of your model very difficult."

https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.26.054401

EVALUATED HEAT FOR THE NON-GAUSSIAN BEAM DUE TO THE RF HARMONICS CAVITIES



By courtesy of Alexis Gamelin

- The harmonic cavities are a powerful tool in particle accelerators for controlling and optimizing the bunch length. By adjusting the voltage and phase of these cavities.
- The shape of the electron beam distribution also changes, from a Gaussian shape without HC to a non-Gaussian with HC.

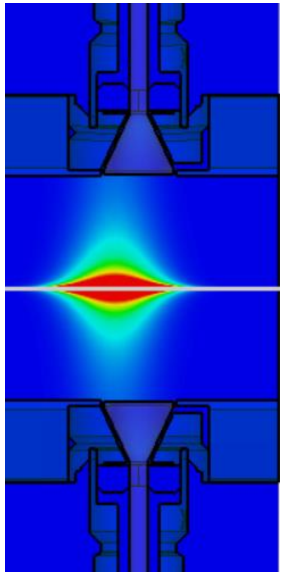
CONCLUSION

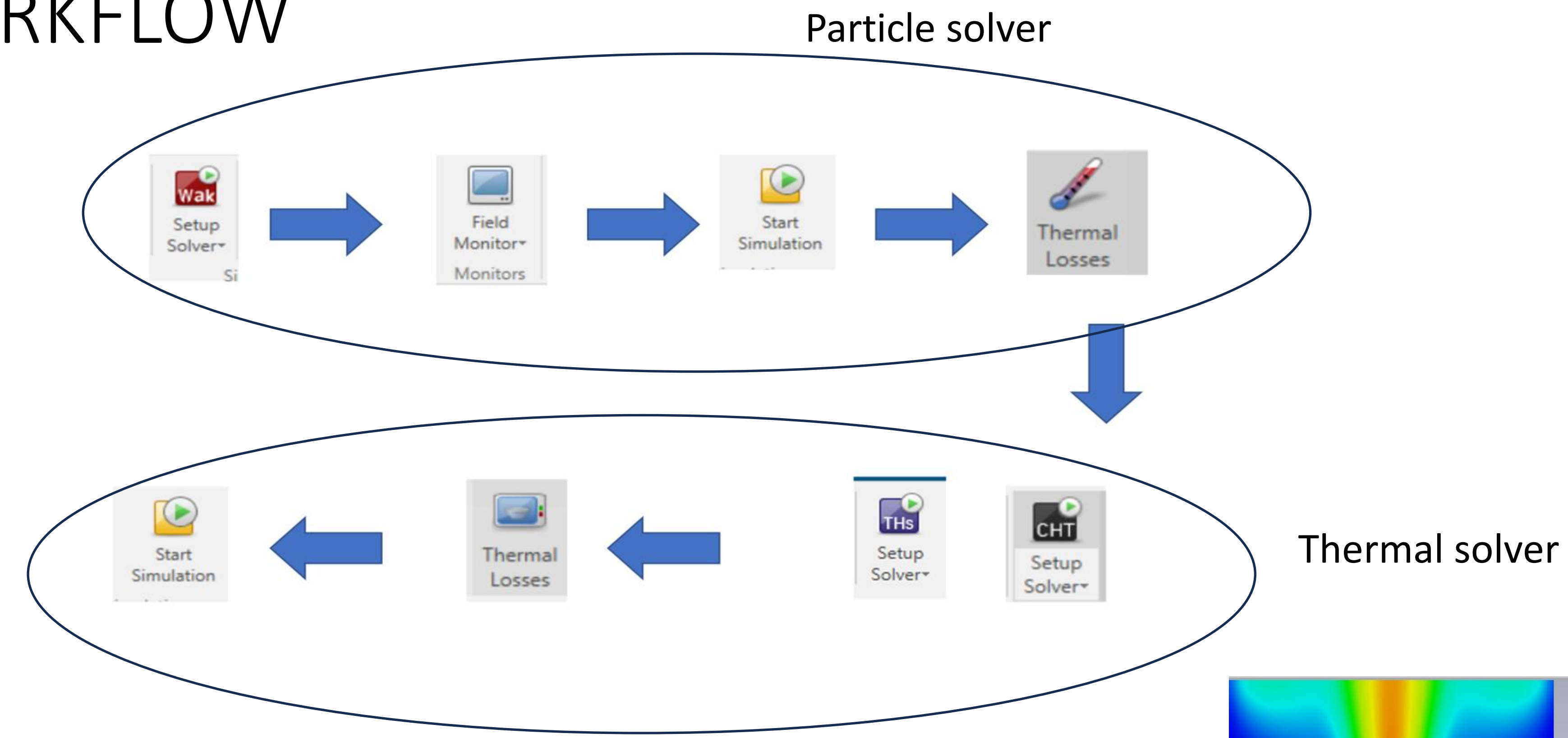
- ✓ CST is a good tool essential for the design and optimisation of particle accelerators components .
- ✓ The multiphysics coupling: Integrates electromagnetic fields, thermal dynamics, and structural mechanics simulations, providing a comprehensive view of complex interactions.
- ✓ Compatible with other simulation software and CAD tools, easy to import export models and results

- Mastering the advanced features and capabilities of CST tools can be complex and time-consuming.
- Complex simulations, especially those involving multiphysics coupling, can be very time-consuming and require advanced technical skills.
- Detailed and precise simulations may require significant hardware resources, including computing power and memory.

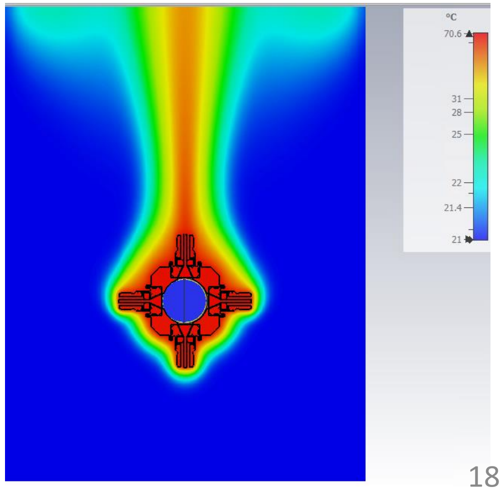
BACKUP

CST WORKFLOW





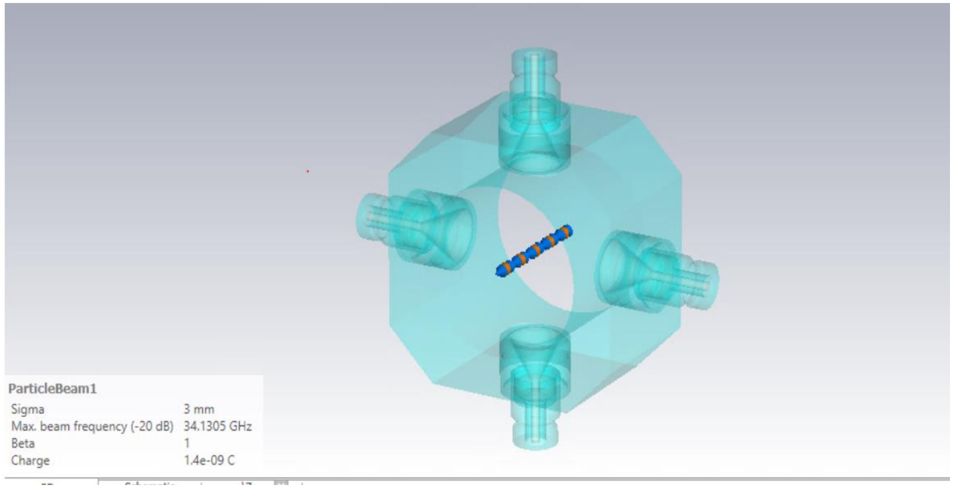
CST allows simulation of not only electromagnetic phenomena but also thermal and mechanical related effects. This helps in understanding the interaction between different physical phenomena.

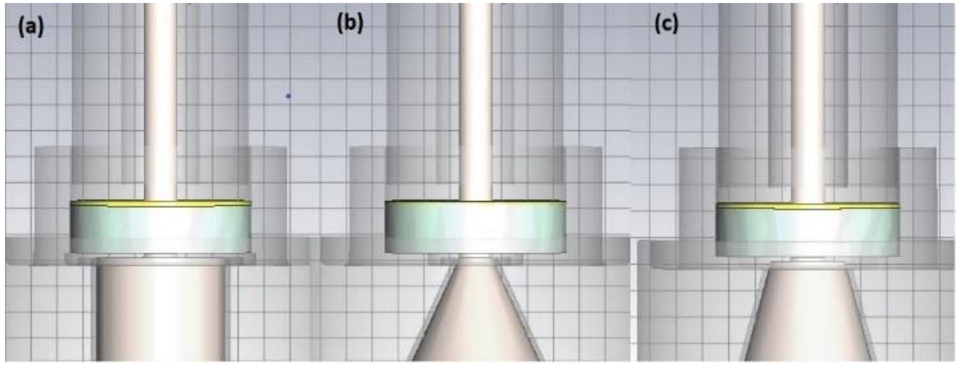


https://indico.cern.ch/event/164082/contributions/246170/attachments/195880/274792/Simulation_packages_and_Review_of_Codes_AG.pdf

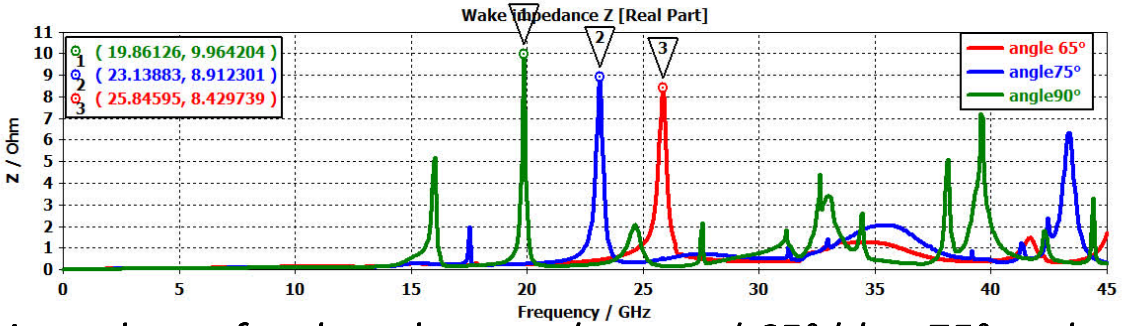
WAKEFIELD SIMULATION

- Compute and determine the real part of longitudinal impedance of your model
- optimize the model to minimize the peaks of impedance or/and shift its en high frequency



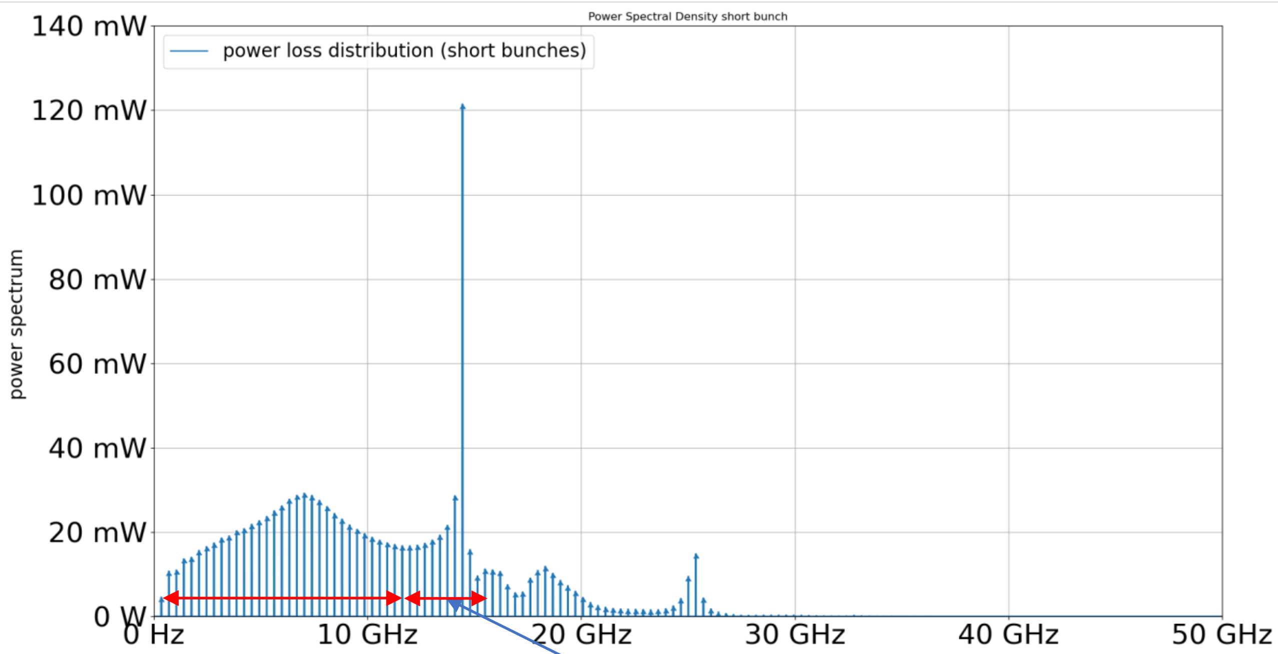


button angle shape simulates (a) Button 90° (b) 65° conical button. (c) 75° conical button.



Real part of impedance for three button shape red 65°,blue 75° and green 90°

POWER SCALING



	Field monitor frequency	frequency interval GHz	Total Loss		Power loss sum in the intreval frequency (W)	CST scaling thermal solver
F1	RW	0<f<11	6,06E-23		1,26	2,08E+22
F2	14,54 GHz	11<f<18	1,15E-19		0,68	5,92E+18
F3	25,49 GHz	18<f<27	1,06E-18		0,31	3,01E+17
F4	32,86 GHz	27<f<54	2,38E-19		0,006	2,81E+16
			2,57E-20	Total power Loss (w)	2,27	

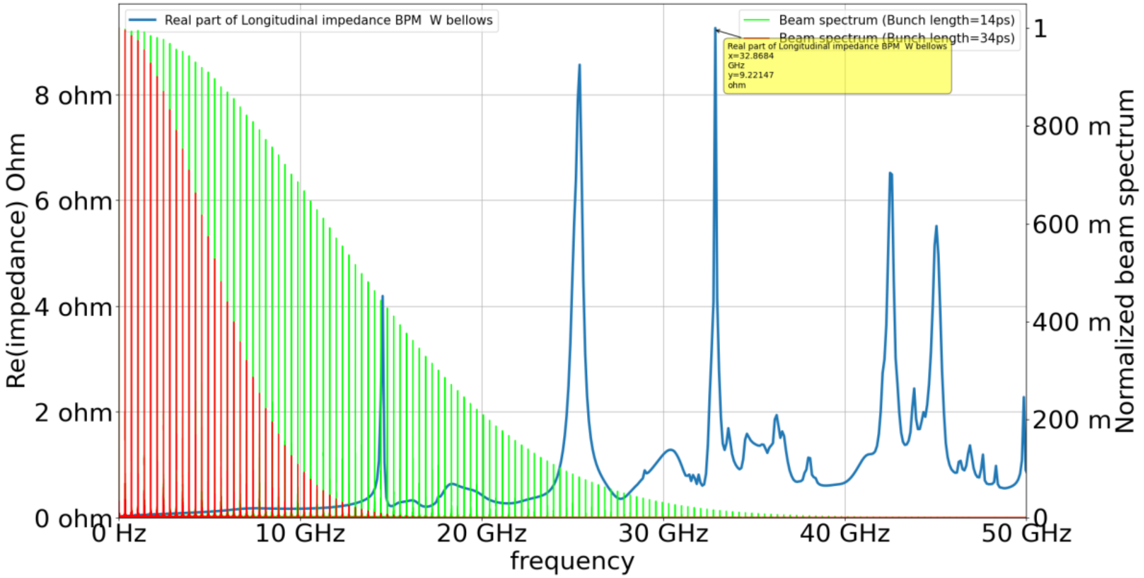
We must normalize the thermal the power loss to the total loss power beam calculate by mbtrack2

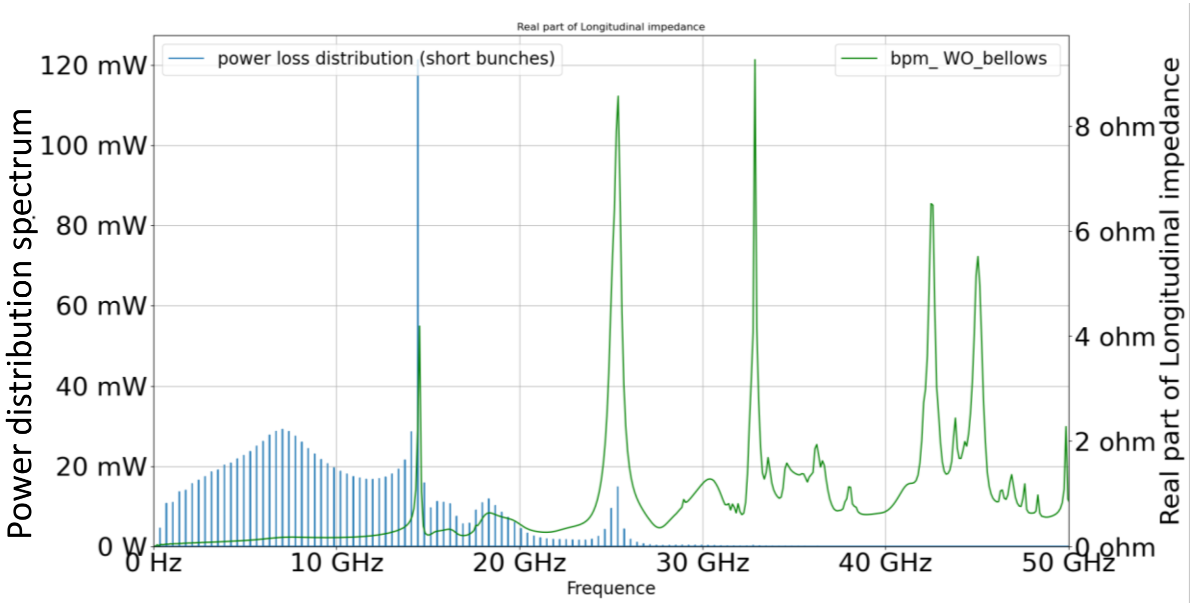
Multi_bunches σ=14ps
Name: loss factor (bunch) [V/pC]= 0.003196
Name: loss factor (beam) [V/pC]= 1.332482
Name: P (bunch) [W]= 2.267484
Name: P (beam) [W]= 2.272795

The total loss represents the sum of the power distribution at each harmonic of the RF frequency

POWER LOSS

- **Power Loss:** Depends on the beam current, charge per bunch, and the real part of the longitudinal impedance.
- **Real Part of Impedance:** Represents resistive effects causing energy dissipation.
- **Bunch Length:** Influences the frequency spectrum of the beam and thereby the interaction with the impedance.





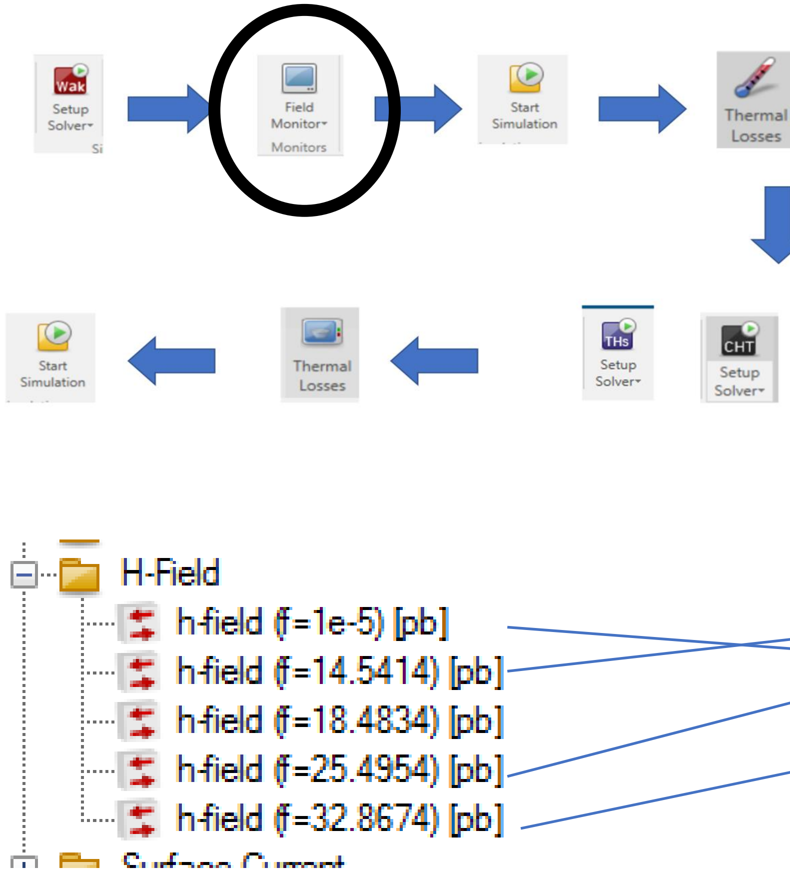
- Short Bunch Length:

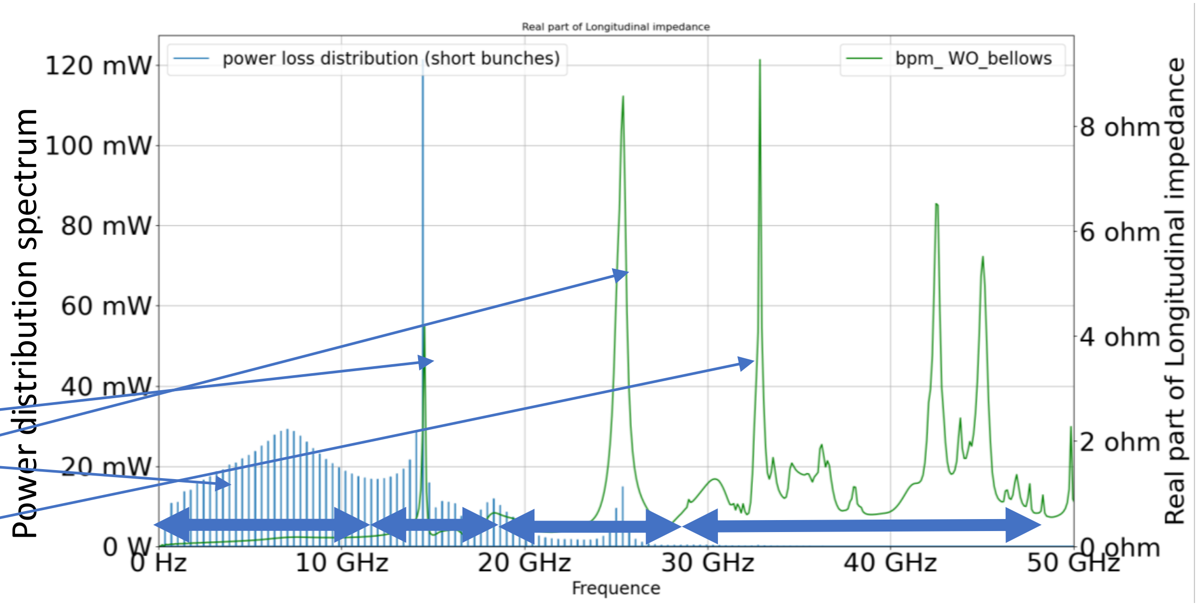
  Leads to a broader frequency spectrum.

  Potentially higher power loss if the impedance is significant at high frequencies.
- Long Bunch Length:

  Results in a narrower frequency spectrum. Lower interaction with high-frequency components of the impedance, potentially reducing power loss.

MONITORS AND FIELD PROBES

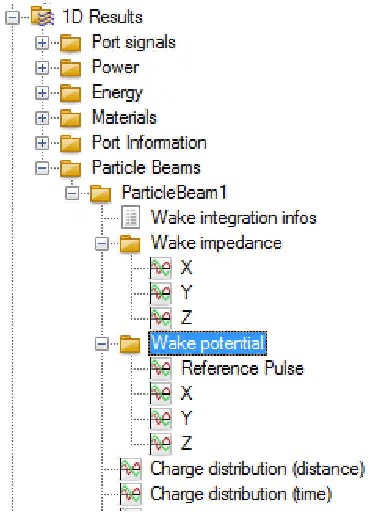


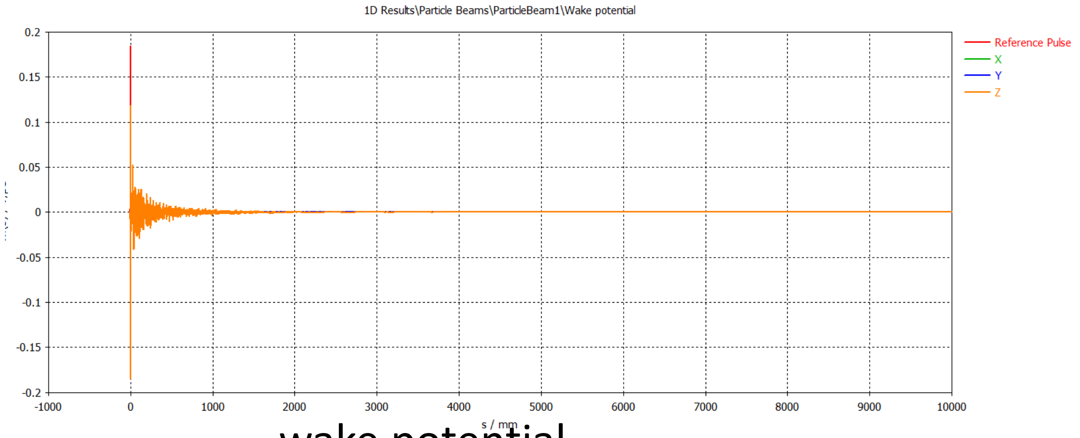


The more monitors you put in, the more you increase the resolution. On the other hand, you increase the calculation time.

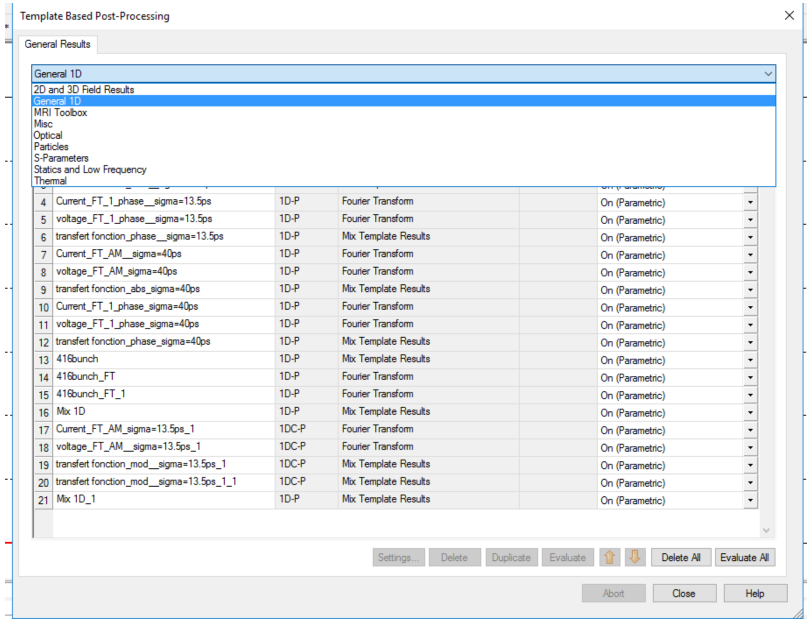
•Placing field monitors at peak frequencies makes it possible to accurately quantify the contribution of each peak to power
• Place on monitor in low frequency permits to estimate the power loss due to the resistive wall loss

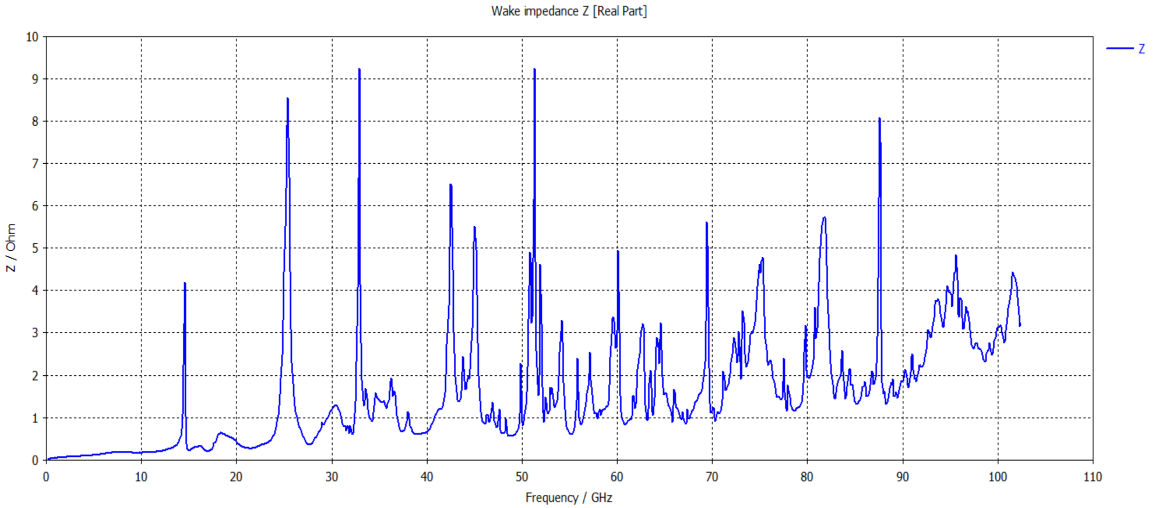
Simulation results





wake potential



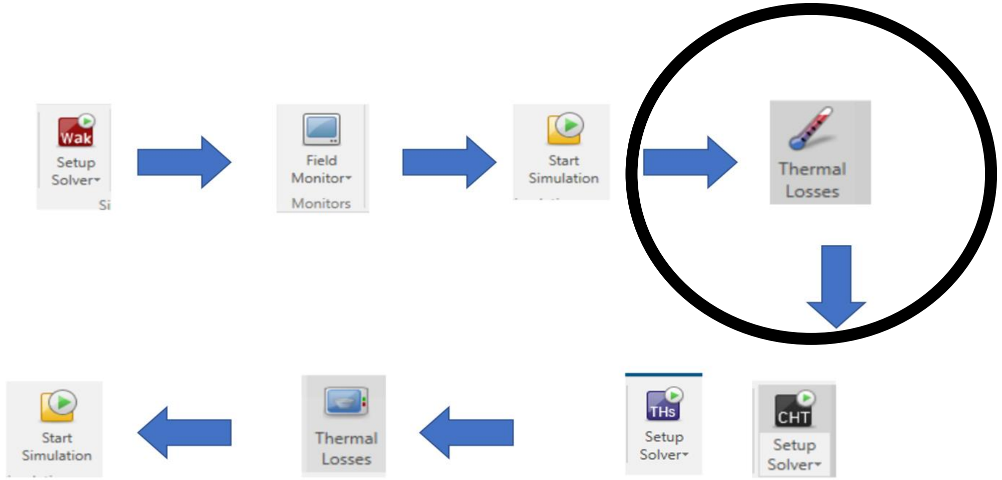


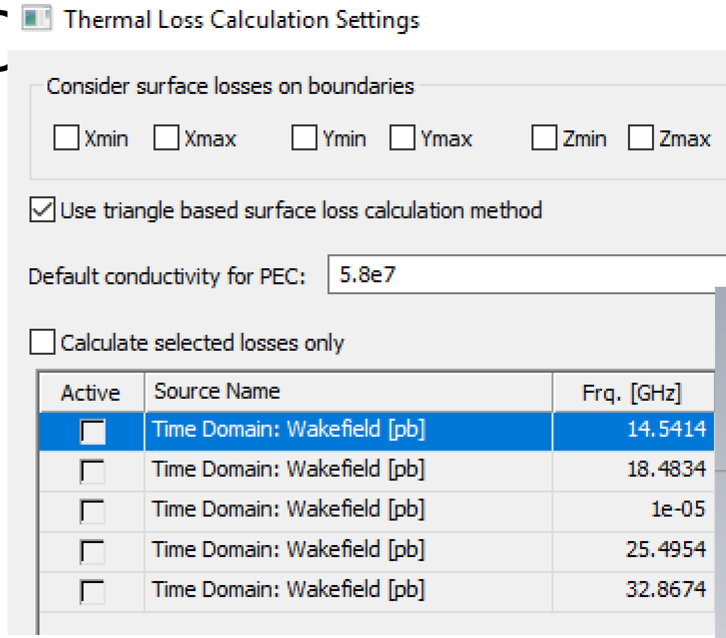
longitudinal impedance

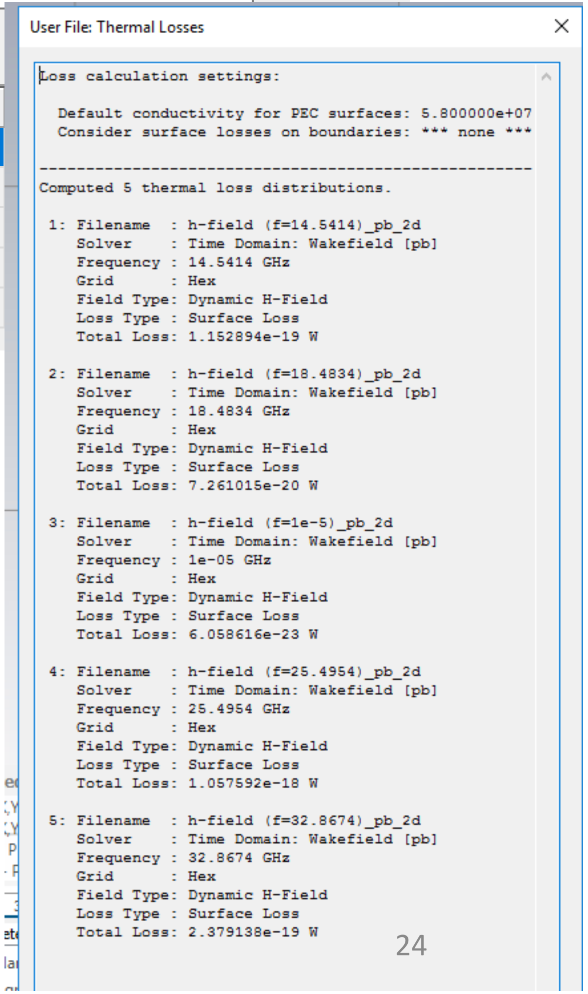
CST directly gives important results by default such as the value of the longitudinal impedance or the wake potential. others are accessible via the post-processing menu

other simulations with an increase in the number of meshes must be done to validate the convergence of your results

THERMAL LOSS CALCULATIC



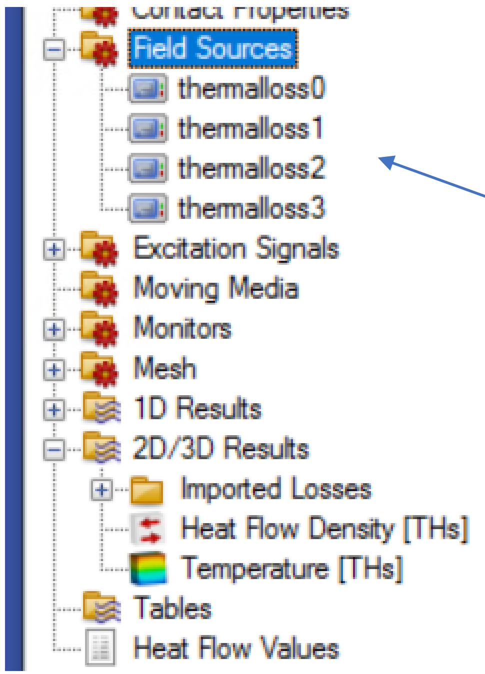




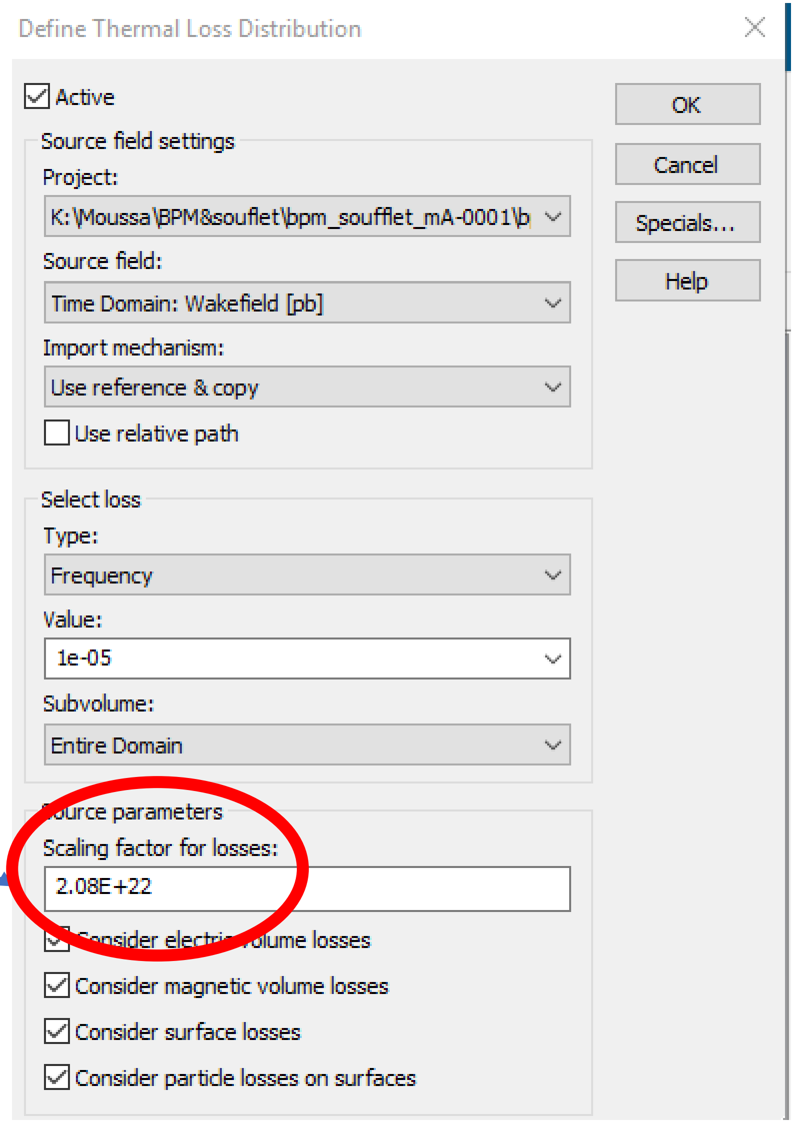
- The thermal loss (power dissipation) in the CST Wakefield solver involves determining how much electromagnetic energy is lost by the beam at the frequency determined by the field monitors.
- *P*loss can be calculated by integrating the power density over the volume of the structure:
- In CST, this integration is often done automatically, and the software provides the dissipated power directly by bunch .

THERMAL SIMULATION

Setting up source fields in the thermal solver within CST Studio Suite involves specifying the power loss data obtained from an electromagnetic simulation as heat sources in the thermal analysis.

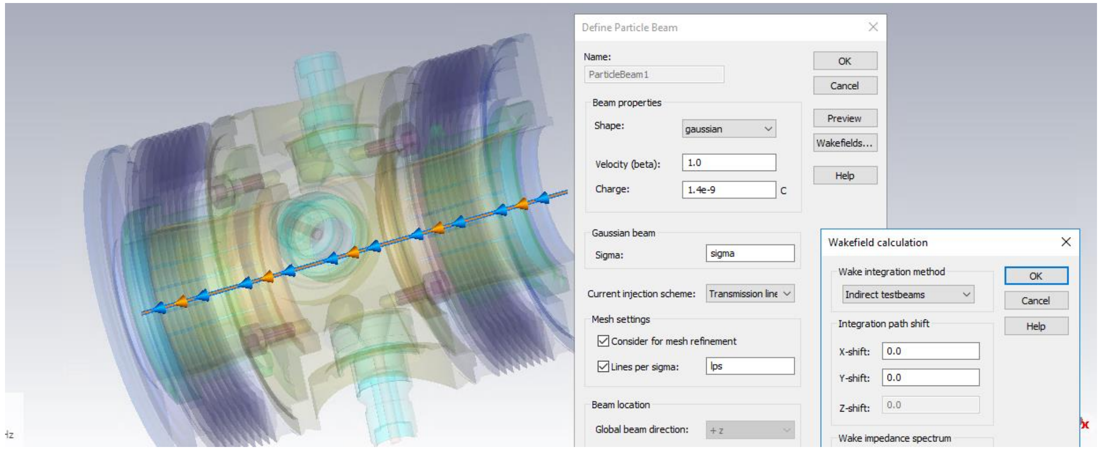


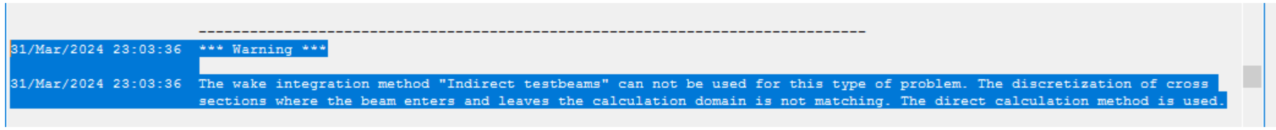
You need to import all power loss data as heat sources. Do not forget to enter the scaling factor in order to normalize the power of each monitor



BEAM CONFIGURATION

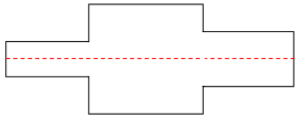
The Wake Integration Method is a crucial tool in the CST Wakefield Solver for analyzing the effects of wakefields in particle accelerators





Direct

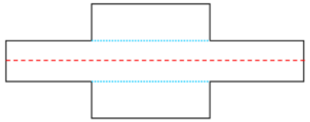
The direct method is the most general method but also less accurate than the two indirect methods. It is used if the particle beam is not ultrarelativistic, or if an indirect method is not applicable.



The wake potential is computed by an integration along an axis parallel to the beam axis.

Indirect testbeams

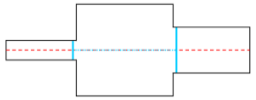
This is the most accurate integration method. It can be used if the beam has an ultrarelativistic velocity and the beam tubes cross section at the entry boundary equals the cross section at the exit boundary. In addition the structure must not be concave which means basically that the cross section of the part between the beam tubes must be larger than the tubes cross section. As a consequence a collimator cannot be treated with this integration method in general. The method is described more detailed in [2].



The wake potential is computed via recording the longitudinal field values on the extruded shell of the beam tube in the discontinuous region (blue lines).

Indirect interfaces

If the cross section of the beam tube varies at the entry and the exit boundary, one can choose this method for ultrarelativistic beams. The method is described more detailed in [3].



The wake integration in the discontinuous region is done directly on an axis parallel to the beam (dotted blue line). For the tube regions the wake potential share is considered by a computation on the interface areas (thick blue lines).

CST switch automatically to "direct integration method" with just a warning message in the log file and no stopping the simulation.