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KLYC. THE 1D/1.5D LARGE SIGNAL COMPUTER CODE FOR THE KLYSTRON SIMULATIONS. USER MANUAL.

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Abstract

Almost all the accurate and efficient 2D large-signal codes for the klystron simulations are proprietary and are not freely available to the wide klystron community. The klystron code KlyC1D/1.5D has been developed at CERN recently, as an attempt to bridge the gap between the fast, but approximate 1D models and the time/resource consuming PIC codes. Here the notation 1D/1.5D is related to the fact that in KlyC one can choose between a 1D or 2D map of the electric field (RF cavities and space charge), whilst the particle motion is one-dimensional. KlyC is available in the public domain. This manual should help the users to start with KlyC simulations.

Geneva, Switzerland
24 October 2018

Introduction

A number of computer codes for the klystrons simulations have been developed in the past. These codes can be split into three categories depending on the complexity, completeness of the model and computational techniques being used. 1D codes like AJDisk, and KlypWin operate in an idealized environment, where parameters of the RF cavities and space charge forces do not depend on the transverse position of an individual electron trajectory. 2D large-signal codes like TESLA, Klys2D and FCI account for all radial effects in the presence of an arbitrary solenoidal magnetic field. To economize on computation time, these codes use different approximations or external simulations of the electric field in RF cavities and drift tubes areas. Particle-In-Cell (PIC) codes like MAGIC2D/3D and CST/3D provide complete and self-consistent field solutions using fine discretization in space and time throughout the entire device. Unfortunately, the accurate and efficient 2D large-signal codes are proprietary and are not freely available to the wide klystron community. The klystron code KlyC1D/1.5D has been developed at CERN recently, as an attempt to bridge the gap between the fast, but approximate 1D models and the time/resource consuming PIC codes. Here the notation 1D/1.5D is related to the fact that KlyC can choose between a 1D or 2D map of the electric field, whilst the particle motion is one-dimensional.

The KlyC computational algorithm is organized in such a way that the interaction between the electric field of the RF cavities, the space charge field and the longitudinal particles movement are self-consistent. During the first iteration, the electron beam will be modulated in the input cavity and propagate along the tube without taking the space charge forces and the RF cavities electric field into account. During the next iteration, the obtained longitudinal charge density modulation will generate initial distribution of the space charge field, excite the electric field in the cavities and the drift tubes, which in turn will affect the beam dynamic. Such a process will be repeated until the gap voltage in the output cavity is converged, providing specified residual difference between the two last iterations.

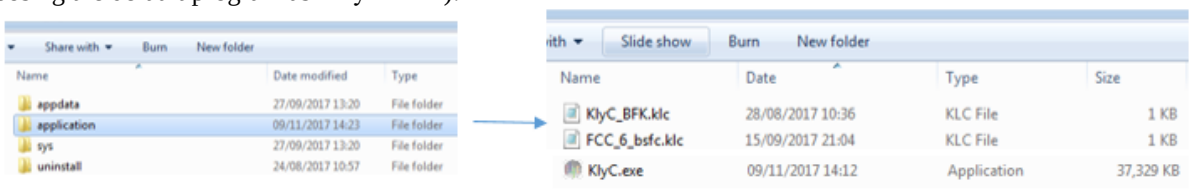
In KlyC/1D charged particles are represented by the disks. In KlyC/1.5D, the set of rings with different radii form the equivalent array of charged particles at the emission plane. The rings radial spacing is equidistant and each ring has an identical charge density, so that for the given beam radius, current in each ring will depend on the number of rings and its radial position. Through the propagation along the tube, each ring will preserve its radial position. The communication between the rings comes from the common RF field in the cavities and drifts to which they contribute individually.

KlyC is available in the public Domain. To receive the access to the code and installation instructions, please contact to the developers directly via emails: Jinchi.Cai@cern.ch ; Igor. Syratchev@cern.ch.

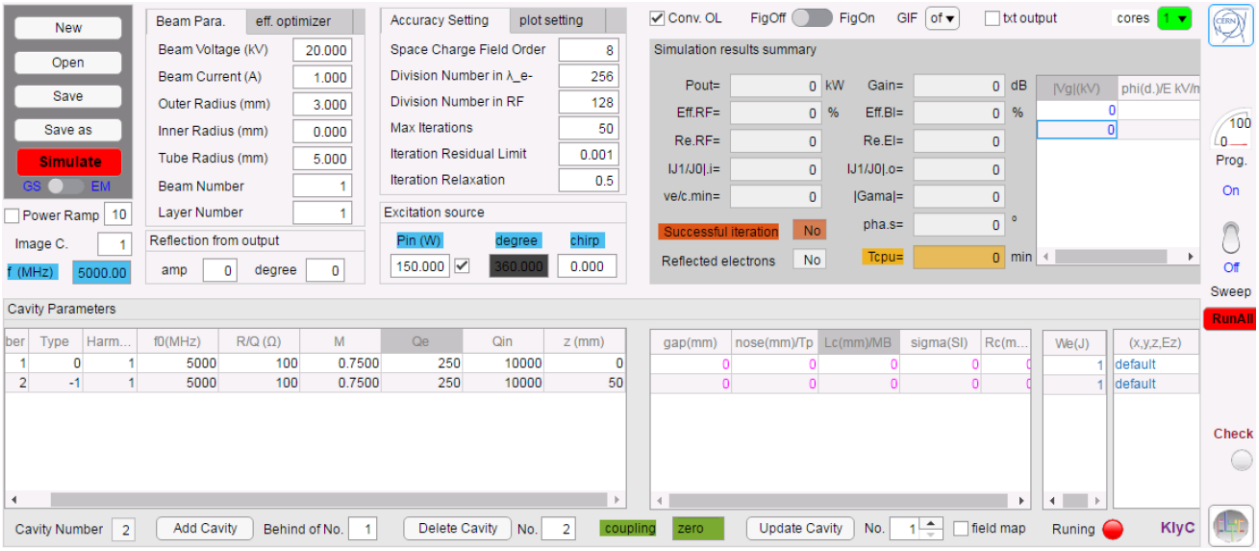
Content:

1. Getting started

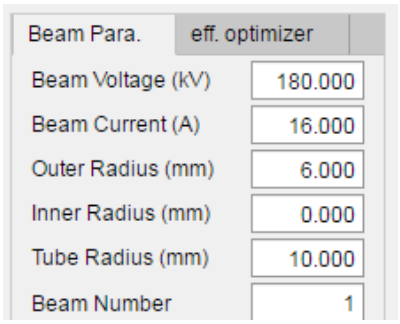
After the KlyC installation into the selected folder, open the folder. The KlyC executable file is located in the 'application' folder. Double click on the file 'KlyC.exe' to start (One can also double click klc file to open KlyC by choosing the default program as 'KlyC.exe'):



The KlyC GUI window will be opened:



As an illustration, we will use next the 5 cavities, low perveance, 2 MW L-band klystron. The tube has been designed using the 'classical' bunching method. First, we specify the operating frequency: f (MHz) 1000.0 ; the input power: Pin (W) 60.000 ; the beam and drift tube parameters:



For the klystron simulations, the box located next to the value of the input power shall be checked. In the case of the hollow beam, the 'Inner Radius' of the beam shall be specified as well (0.0 by default).

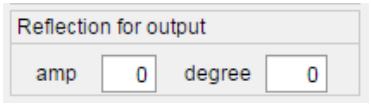
The KlyC particles emission algorithm is based on the model that uses emission from the metal surface (similar to the one used in the PIC CST/3D). In this case the beam kinetic energy will be fractionally converted into the DC potential of the beam space charge (the effect known as the space charge depression). The amount of converted energy will depends on the beam power, the perveance and the drift tube filling factor (space charge). To enable such an emission mechanism (recommended), the value of the 'Image C' shall be set to -1: If Image C = 0, then the beam will have the full kinetic power as is specified in the beam parameters table.

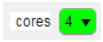
Image C. -1

In 2D simulations, by default, the current density across the beam cross-section is constant. The user can introduce the radial variation of the beam current density as a linear function by specifying the chirp value: , 

In this case, chirp (α) is defined as: $\alpha = \frac{J(r_{m2})-J(r_{m1})}{J_0} = \frac{J(r_{m2})-J(r_{m1})}{I_0/\pi/(r_{m2}^2-r_{m1}^2)}$;

The klystron can be simulated using the option of the not perfectly matched RF load. In this case the normalized amplitude (voltage) and phase of reflection shall be specified in:



KlyC supports multi-core processors (up to 4): 

For the 2D simulations this option allows to increase the simulations speed by about 30% to 100%, depending on the case.

Upon completing the simulations, the KlyC can generate multiple graphics, animations and extract the data into text file(s). All these can be enabled by using the corresponding buttons on a panel:

2. RF cavities and klystron layout.

The general cavities parameters and klystron layout can be introduced directly into a cavity parameters table:

Cavity Parameters

Number	Type	Harm...	f0(MHz)	R/Q (Ω)	M	Qe	Qin	z (mm)
1	0	1	1000	182.8959	0.9225	334	1.6428e+04	0
2	1	1	1006	116.9999	0.8930	95000	1.9768e+04	480
3	1	1	1016	102.0570	0.8192	95000	1.9816e+04	1630
4	1	1	1030	123.6318	0.9518	95000	1.6970e+04	2400
5	-1	1	1000	180.3864	0.9325	50	1.4787e+04	2730

The cavities types are as follows: 0 is the input cavity, 1 is the bunching cavities and -1 is the output cavity. If the harmonic cavity is used, the harmonic number of this cavity shall be specified in a third column. The **frequency** (column 4), the external **Q factor** (column 6) and the **cavity position** (column 9) have to be defined by the user.

In the simulations, KlyC uses 1D/2D maps of electric field in the drift tubes and cavity areas. KlyC suggests few options to generate these maps.

1. Gaussian approximation.

In this case the user has to specify directly each cavity's impedance (R/Q), beam coupling (M) and intrinsic Q factor (Qin). Impedance and beam coupling are defined as:

$$\rho = [\int_{-\infty}^{+\infty} \frac{|e_z^*(z)|}{\sqrt{\omega_0 \varepsilon_0}} dz]^2, |M| = |\frac{\int_{-\infty}^{+\infty} e^{-j\omega_0/v_{e0} z} e_z^*(z) dz}{\int_{-\infty}^{+\infty} |e_z^*(z)| dz}|$$

Following, the longitudinal distribution of the normalized electric field will be reconstructed:

$$e_z^*(z) = k\sqrt{\frac{\rho k_0}{\pi \eta_0}} e^{-k^2 z^2}, k = \frac{1}{2}\frac{\omega_0/v_{e0}}{\sqrt{-\ln|M(\omega_0/v_{e0})|}}$$

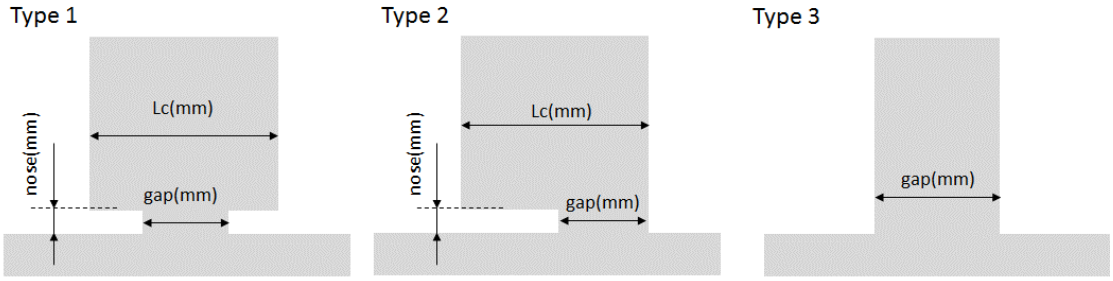
This electric field distribution holds only the longitudinal variation and is constant across the beam tunnel. This option is similar to the one used in 1D computer code AJDisk.

2. KlyC internal cavity calculator.

The specially developed eigenmode solver is integrated into the KlyC. To facilitate the RF cavities parameters calculation, the KlyC cavity calculator supports three the most common topologies of RF cavities that are used in the

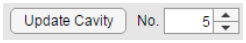
klystrons. In the EM module window, for each cavity, the user has to define three geometrical parameters and specify the conductivity of the material being used:

gap(mm)	nose(mm)/Tp	Lc(mm)/MB	sigma(SI)	Rc(m...
36.5000	9.4000	102	58000000	80.0753
46.2000	14.1000	69	58000000	106.4...
63.9000	0	63.9000	58000000	113.0...
25	8.1000	63.9000	58000000	91.8979
33	9	105	58000000	72.3853



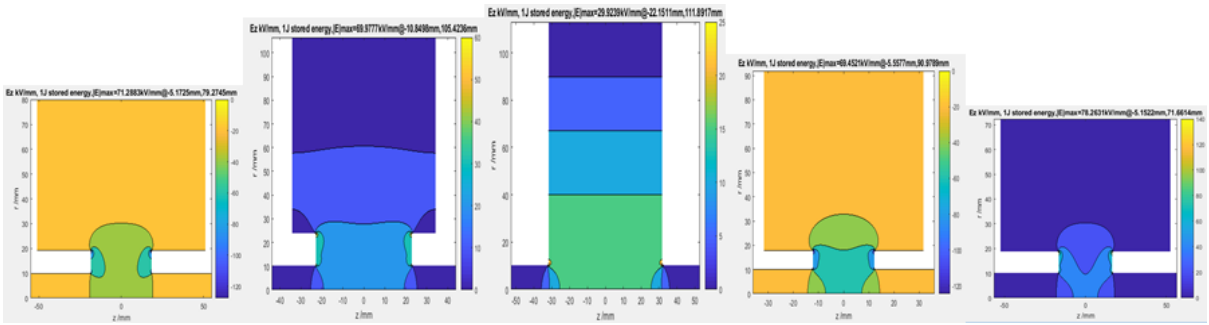
Gap should be specified as a negative number

Nose should be set equal 0 and Lc=gap.

When the geometry of the given cavity is defined, click on 

. KlyC will run eigenmode solver and adjust the cavity radius (Rc) to satisfy the cavity frequency specified in the cavity parameters table. It will calculate R/Q, beam coupling M and Qin. The calculated values will be automatically updated in the cavity parameters table. The values of R/Q and M are calculated as the ones averaged over the beam cross-section. If the field map box is checked: 

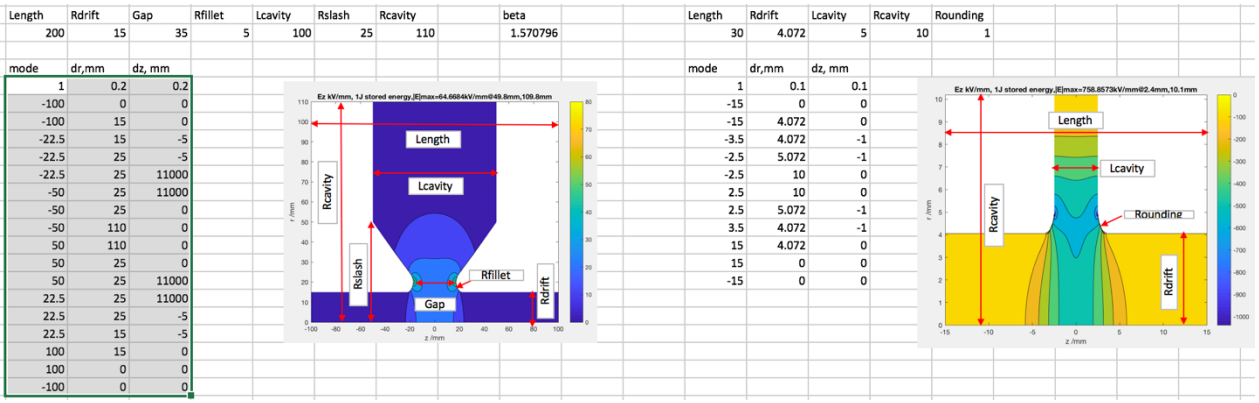
KlyC will generate the graphical information about the cavity. The Ez field maps in the 5 cavities simulated by KlyC cavity calculator:



In general, it is not necessary to update the cavities every time using 'update cavity' button. When the klystron simulation is started, KlyC will update all the cavities automatically. In all the cases, the cavity position with respect to the one defined in the cavity parameters table will correspond to the gap center. If the user made a topological mistake during cavity geometry specification, the 'check' indicator (bottom right on the GUI window) will blink yellow.

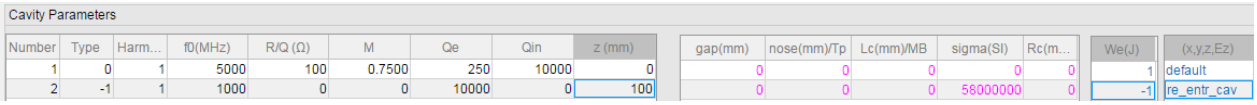
3. KlyC EM module.

This option allows the user to generate an arbitrary cavity geometry using geometric primitives like lines and circular arcs. We may suggest the users to use Excel to generate the parametric models:

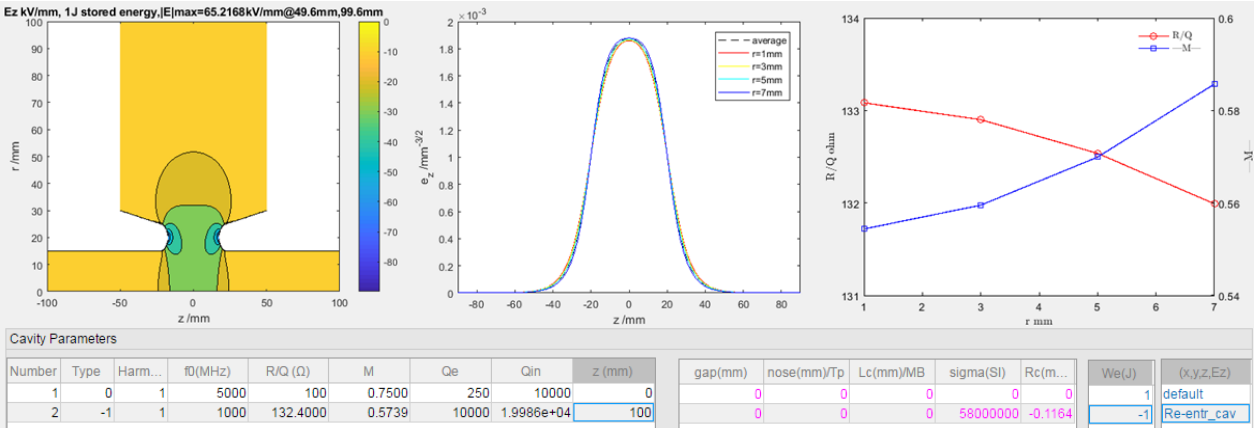


The area with grey background contains the data that shall be copied (or directly generated) into designated txt file that will be used by KlyC to generate and simulate the cavity. In the first line one shall specify the mode number to be simulated, the mesh step length in z direction and the mesh step length in r direction (mm).The geometry should start and finish with min (z) and min (r) points (bottom left corner). From that position, in a clockwise direction, the geometry nodes (first column 'Z'; second column 'R') and primitive's type (third column) shall be introduced one by one. All dimensions are in mm. The primitive's type at its intersecting point (clockwise) shall be specified as follows:
- The straight vertical, or horizontal line: '0'
- The arc: +r or – r. Here r is arc radius, '+' if the arc goes clockwise and '-' if it goes anti-clockwise.
- The tilted line is defined as an arc of a very large (~ x100 of the line length itself) radius.

The file with geometry data shall be saved (created) in the same folder, where the klc project file is located.
To read the geometry file in KlyC, the name of the file without extension shall be typed into the last column (x,y,z, Ez) of the parameters table and in the We(J) column the user shall put negative number (-1). Please check that drift radius in the cavity file is the same as the one specified in the project. **Note**, keep 'default' in (x,y,z, Ez) column if the parameters table and/or the KlyC cavity simulator are used only. Next we used the re-entrant cavity as an example:



Here (cavity #2) we specify the cavity type, harmonic number, frequency, position and material conductivity (sigma). The cavity geometry name is 'Re-ent_cav' and We(J) = -1. When 'cavity update' button is pressed, the cavity will be simulated:



In the column Rc(mm) KlyC will report on the frequency discrepancy between the simulated value and the one specified in the table: $(F_{sim}\text{-}f0)/f0$. The user can tune the frequency by modifying the cavity geometry. To our experience, it is not necessary to tune the frequency difference to be '0', as for simulation KlyC will use the frequency from the table (f0), whilst R/Q, M and Qin are slow varying functions with respect to the cavity frequency.
Even if the cavity simulations could be rather fast (few seconds), they will be repeated at every iteration for every cavity. To avoid this, we recommend to run only few (2-3) iterations with box 'txt output' being checked. The KlyC will save all the Ez field distribution(s) into txt files with names KlyCcavity# (# is a cavity number). Next, one can use

these files (please re-name it, if in use) to import file into the KlyC. In this case, the We(J) value associated with this cavity shall be put to '0':

Cavity Parameters

Number	Type	Harm...	f0(MHz)	R/Q (Ω)	M	Qe	Qin	z (mm)	gap(mm)	nose(mm)/Tp	Lc(mm)/MB	sigma(SI)	Rc(m...	We(J)	(x,y,z,Ez)
1	0	1	5000	100	0.7500	250	10000	0	0	0	0	0	0	1	default
2	1	1	1000	0	0	10000	0	0	0	0	0	58000000	0	0	R_cavity2
3	-1	1	1000	132.4000	0.5739	10000	1.9986e+04	100	0	0	0	58000000	-0.1164	-1	Re-entr_cav

The cavity (R_cavity2) now will be simulated using this option:

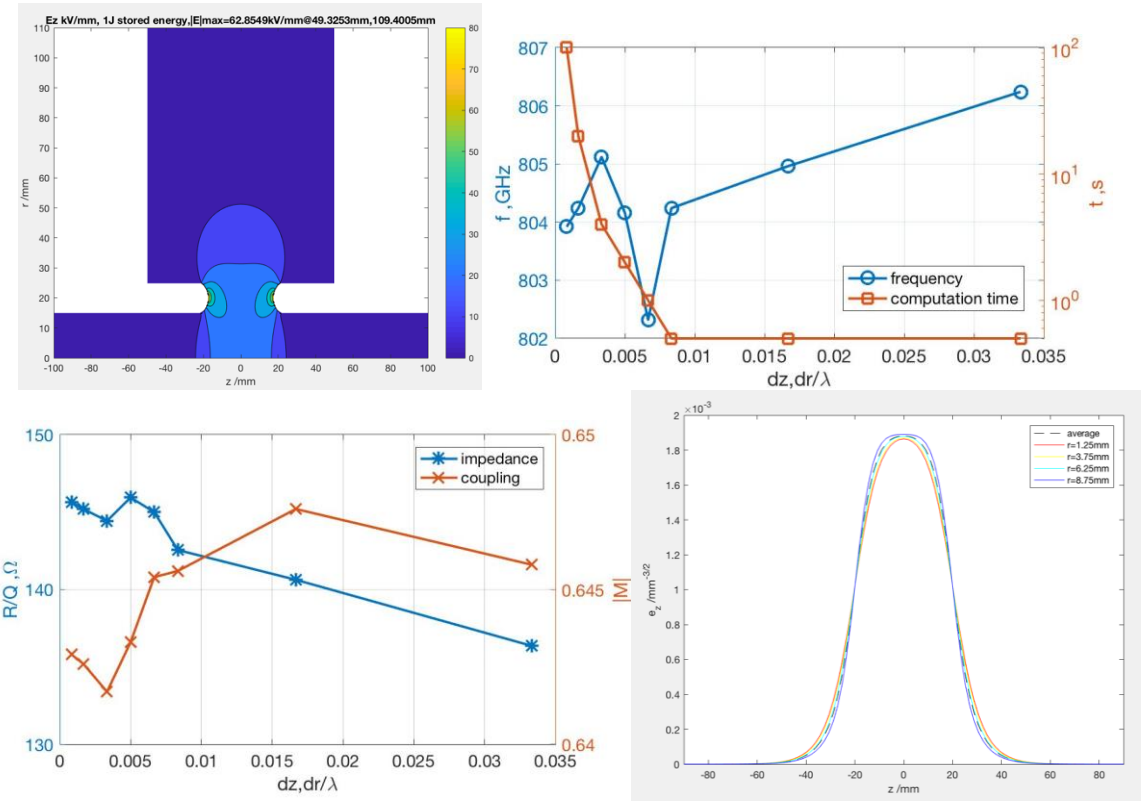
Cavity Parameters

Number	Type	Harm...	f0(MHz)	R/Q (Ω)	M	Qe	Qin	z (mm)	gap(mm)	nose(mm)/Tp	Lc(mm)/MB	sigma(SI)	Rc(m...	We(J)	(x,y,z,Ez)
1	0	1	5000	100	0.7500	250	10000	0	0	0	0	0	0	1	default
2	1	1	1000	132.3941	0.5739	10000	0	0	0	0	0	58000000	0	0	R_cavity2
3	-1	1	1000	132.4000	0.5739	10000	1.9986e+04	100	0	0	0	58000000	-0.1164	-1	Re-entr_cav

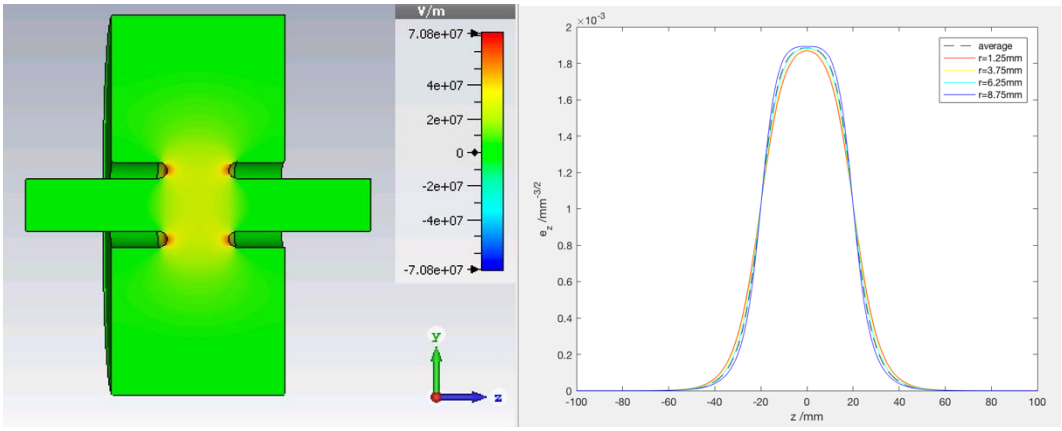
The last thing to do, the user shall manually put the Qin value of the simulated cavity to be the same as the one simulated by KlyC EM module.

Note, in **2D** simulations KlyC will save filed information only for the number of radial layers that have been specified. If the different radial layers number will be used in simulations later on, KlyC will interpolate field distribution using the saved field data.

To demonstrate the KlyC EM module performance we choose the re-entrant cavity with rounded noses. In this case we have used the square mesh type (dz=dr) and studied the parameters convergence and simulation time as functions of the model resolution:



As a general impression, KlyC EM module does converge smoothly and needs to be refined further to improve the accuracy. That will lead to very long simulation time. However; as a compromise, the discretization dr;dz/dλ=0.005 can be recommended (it takes few seconds to simulate on the ordinary laptop). The same cavity has been simulated in CST/3D:



The comparison between the two codes is shown next. The KlyC data is taken for dr;dz/dλ=0.005

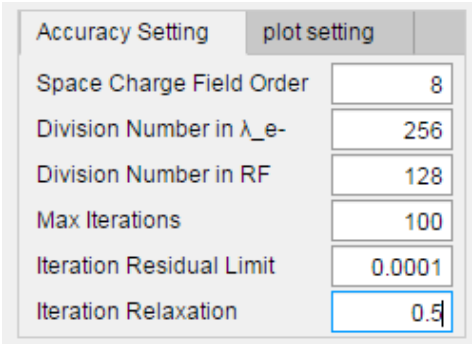
	Frequency. MHz	R/Q, Ohms	M	Qin
CST/3D	801.9	147.6	0.647	19229
KlyC EM module	804.1	146.0	0.643	19337

The 0.2% difference in frequency is observed. However, KlyC uses the user defined frequency for simulations, so that these results can be used as an information about the KlyC EM convergence accuracy. The R/Q, M and Qin discrepancies stay within 1%. To our experience, such a difference can affect the tube performance at a level of 0.1%.

4. Filed map import from HFSS and/or CST.
This last option allows the user to design the cavity using eigenmode solvers of HFSS and/or CST. The instructions of how to import the filed maps from these codes into the KlyC are given Appendix I.

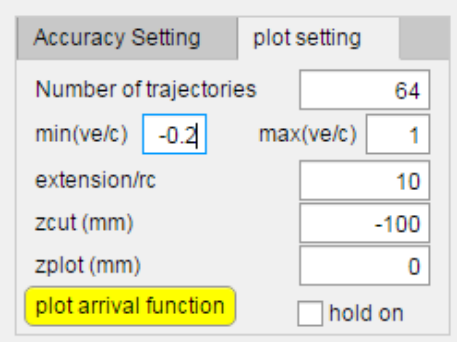
3. Model discretization (accuracy) settings.

In the KlyC, the model discretization is controlled by selecting the number of spatial divisions per electronic wavelength (Nz), the number of emitted particles per RF period (Nt) and the number of harmonics to be used in calculations of the space charge field (Ns). Simulations will be completed when the requested iteration residual limit is reached, or the number of iterations exceeds the specified limit. The residual limit is measured using the convergence of the gap voltage in the output cavity. The iterations convergence process can be optimized by adjusting the iteration relaxation parameter (0.5 by default). This parameter controls the weight which will be used by KlyC to account for the result of the given iteration when moving to the consequent one. For every case relaxation parameter can be adjusted (normally <0.5) to minimize the number of iterations (simulation time) to reach the convergent criteria. The model accuracy settings which are recommended for the klystron optimization process are:



4. Plot settings

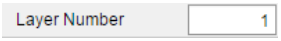
The output graphics and animations generated by KlyC can be controlled from the plot settings menu:

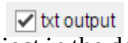


The number of trajectories specifies Applegate diagram, it shall be less than 'Division Number in RF'. The velocities limits control the scale of the pictures and animations related to the bunched beam phase diagrams. The 'extension/rc' allows to specify the length (normalized to drift tube radius) of the drift tube after the output cavity. By default, this parameter is set to 2, in order to minimize the simulation time. Parameter 'zcut' specifies the starting position of the plots which are functions of the longitudinal coordinate. The applications of parameter 'zplot', 'plot arrival function' button and 'hold on' box are explained later in the text.

5. Starting simulations.

Before running the simulations, the user can select between two regimes using 

GS mode is recommended when the cavities parameters have been defined in the cavity parameters table. In this case the 1D cavities filed maps will be generated and used in simulations. **EM** mode shall be chosen if cavities are designed using KlyC cavity calculator/EM module, or when the electric field is imported from the other eigenmode solvers. In this case the 2D cavities filed maps will be generated and used in simulations.
The user can choose between 1D and 2D simulations by specifying the 

If Layer Number =1, the 1D simulations will be executed. If Layer Number >1 (recommended 4, at least), the 2D simulations will be done. If 2D option is chosen, the space charge simulations will be done in 2D, independently of the simulation regime GS/EM.
The results of the simulations will be saved into txt file if the box 'txt output' is checked: 

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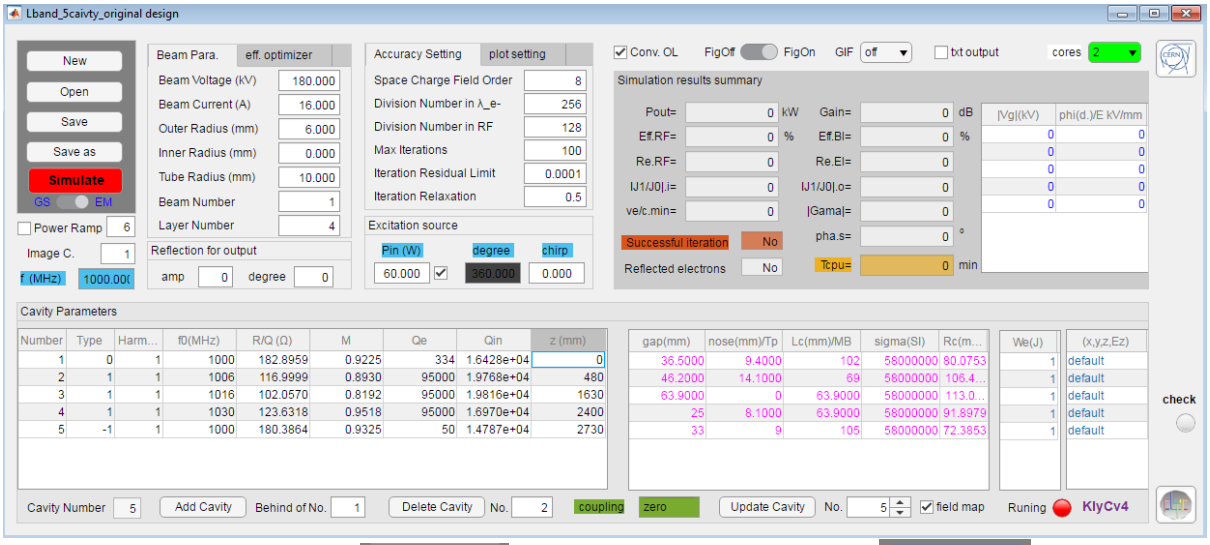
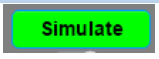
Now the project is fully prepared for 2D/EM simulation. It is recommended to save each project in the dedicated folder, where all the files generated by KlyC will be located after the simulation is finished. When saved, the project_name.klc file will be created. Next time, the KlyC can be started by clicking on the existing *.klc file in the folder.



To start simulations press on the 

button. The button will turn green 

as well as 'Running' indicator: 

It is strongly recommended to check the convergence on line box: 

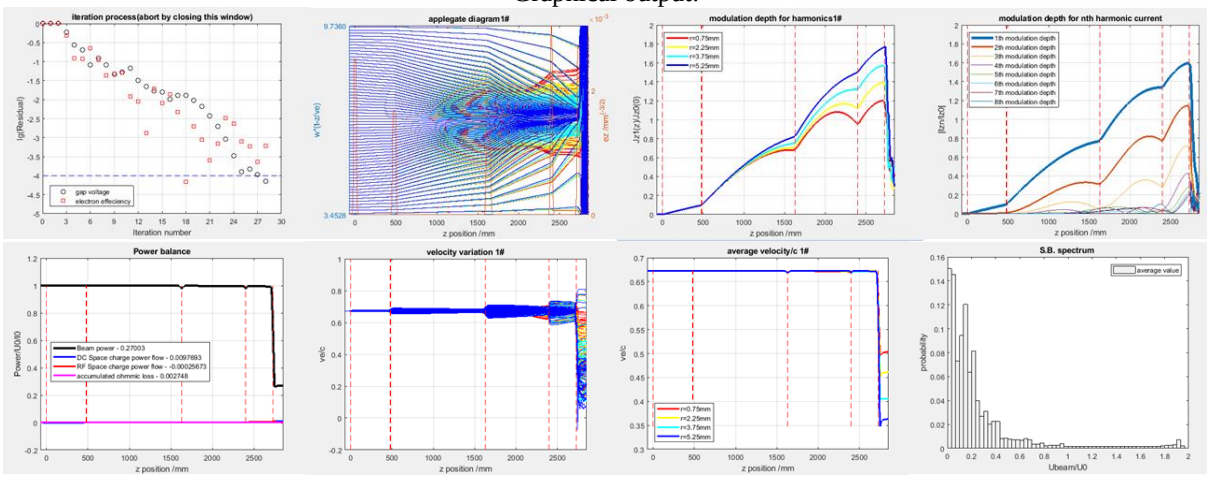
. In this case the iterations progress window will pop up and will allow to monitor the simulation process. If there is need to terminate simulation, it can

be done by closing the convergence history window. When simulation is finished, the 'Running' indicator will turn red.

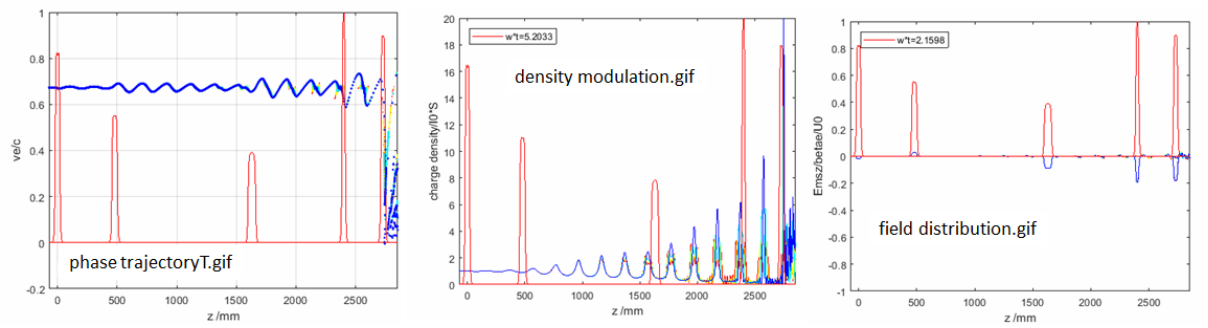
6. KlyC output graphics, animations and data.

If requested, upon completion the simulation, KlyC will generate multiple graphics and animations. The animations are generated as gif files and stored in the project folder.

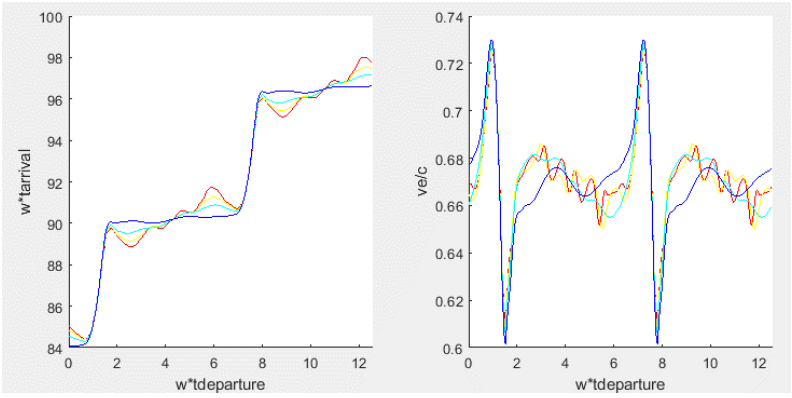
Graphical output:



Animations:



To generate **arrival functions** (time and velocity), the 'hold on' box in the plot setting menu needs to be checked before simulations have been started. Next, the position (zplot) at which the arrival functions will be calculated shall be specified. Finally the arrival function plots will be generated after clicking on 'plot arrival function'. If this operations is repeated for the different zplot value, the new curves will be added to the pictures. The curves will be saved into data files (with value of zplot in the file name) if 'txt output' box is checked.



Note, these calculations require storing a lot of data in a computer memory. That is why, one may consider to use this option if only necessary. The memory cash can be emptied at any time by clicking on 

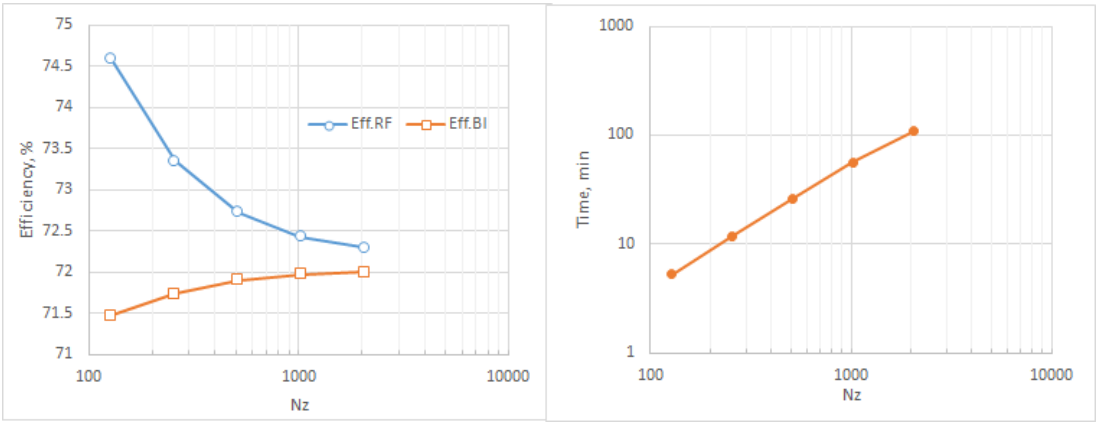
The results of simulations are collected in the 'Simulation results summary' table:

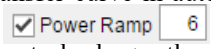
Simulation results summary

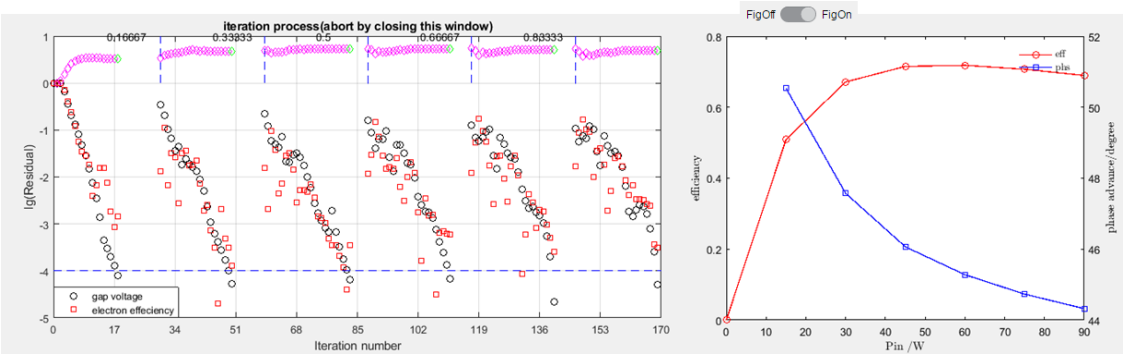
Pout=	2067	kW	Gain=	45.37	dB	
Eff.RF=	73.35	%	Eff.Bl=	71.77	%	
Re.RF=	7.154e-05		Re.El=	0.0006139		
IJ1/J0|.i=	1.202		IJ1/J0|.o=	1.769		
ve/c.min=	-0.07811		|Gama|=	0.6236		
Successful iteration	Yes		pha.s=	45.28	°	
Reflected electrons	No		Tcpu=	15.07	min	

|Vg|(kV)	phi(d.)/E kV/mm
4.2323	0.1994
14.3392	0.8252
33.1952	0.8701
43.4965	2.3890
194.9578	10.1475

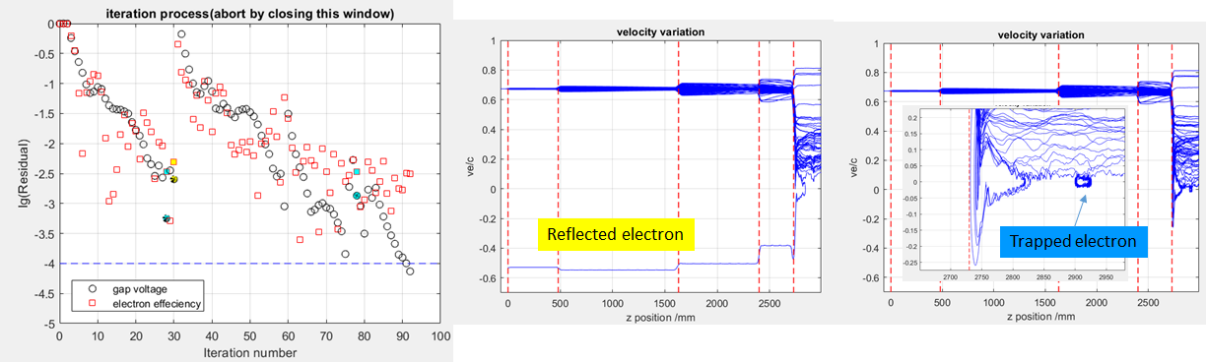
The KlyC calculates the RF power production efficiency using the two methods. The first method (Eff.RF) is based on the direct measurement of the output cavity gap voltage. In the second method (Eff.Bl) the beam power balance is used. Here, the total lost power is calculated as a sum of the spent beam kinetic energy, DC/RF energy of the space charge field in the spent beam and the Ohmic losses in all the klystron cavities. With increasing the model resolution (Nz), the Eff.RF will normally converge to the Eff. Bl value. However this might require significant increasing of the computation time. Thus, we recommend to use the efficiency based on the power balance calculations. 'Pout' and 'Gain' in the summary table are calculated using balanced power.



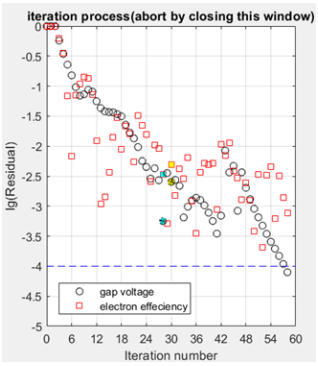
To calculate the power transfer curve in automated regime, check the 'Power ramp' box and select the number of points for the simulation:  Next, specify the value of the maximum power to be used:  , set the itearations number to be larger than N_points x N_1 (N_1 is anticipated number of iterations needed for single simulation) and start simulation:



In the presence of the reflected electrons, the KlyC will have problems with convergence. These reflected electrons could be virtual: the ones that appear shortly during the iteration process only; or the real ones which will persist. The KlyC indicates two types of abnormalities: **reflected** electrons (colored in yellow during iterations process), those who reached the emission plane and **trapped** electrons (colored in blue), those who stay in the simulation volume for more than 10 RF periods.

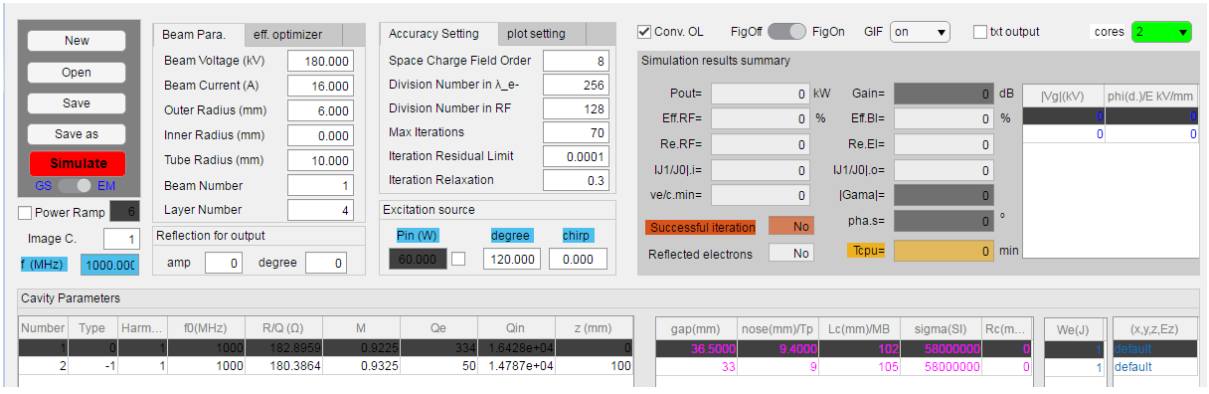


If these effects are numerical artefacts (virtual reflected electrons), the user can try to mitigate them by adjusting the value of relaxation parameter and/or changing the number of layers in 2D simulations. Ultimately, the user can specify position of the plane at which the reflected electrons will be absorbed. The position of the absorbing plane is specified in the plot menu using zcut(mm). In the next example, zcut was set to be between the last bunching and the output cavity:



7. Bunched beam as a power source.

ThKlyC allows to simulate RF circuit being excited by the bunched beam. This option can be used for the IOT design, or for the individual studies of special RF output structures in electron devices. The cavity types here will be limited to type '1' and type '-1'. To enable this option, the 'Pin' box shall be unchecked and the KlyC GUI window will be modified:

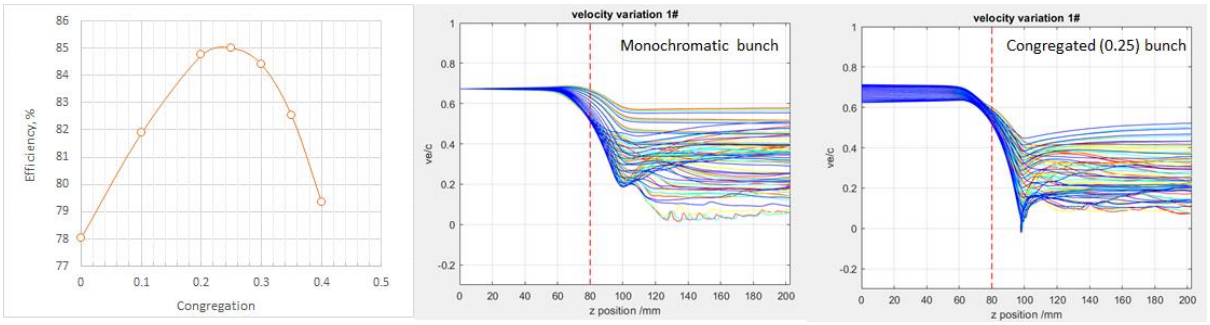


In the given example we have used the output cavity of the klystron that we have introduced before. Even the parameters of first cavity in the table are not used (colored in dark grey), the user has to specify the cavity position, as it will be used as a position of the emission plane.
The modulated current will be represented by individual bunches with constant charge distribution along the bunch. The bunch separation is defined by the operating frequency and the bunch length is specified by the user in terms of the operating wavelength RF phase by putting this value in 'degree' box.
In addition the user can choose, if the bunch should have velocity dispersion along the bunch length using the 'chirp' value. In this case KlyC will generate congregated bunch, where the velocity of the bunch head is lower than the velocity of the bunch tail. The amplitude of congregation (0<chirp<1) will be used to generate the velocity dispersion:

$$U(t_0) = U_{aver}[1 + chirp \cdot \sin(\omega t - \pi)], 0 < \omega t < 2\pi$$

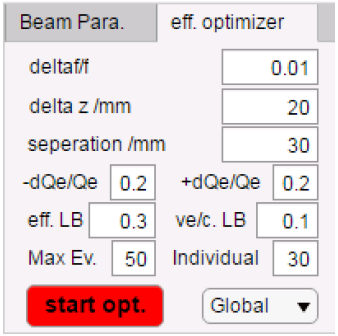
$$I(t_0) = \frac{I_{aver}}{2\alpha}[\text{sign}(\omega t - \pi + \alpha\pi) - sign(\omega t - \pi - \alpha\pi)], \alpha = degree/360°$$

The average kinetic energy of the bunched beam is identical the equivalent DC beam kinetic energy specified in the beam parameters table. In the next example we have studied how the RF power extraction efficiency depends on the bunch congregation amplitude:



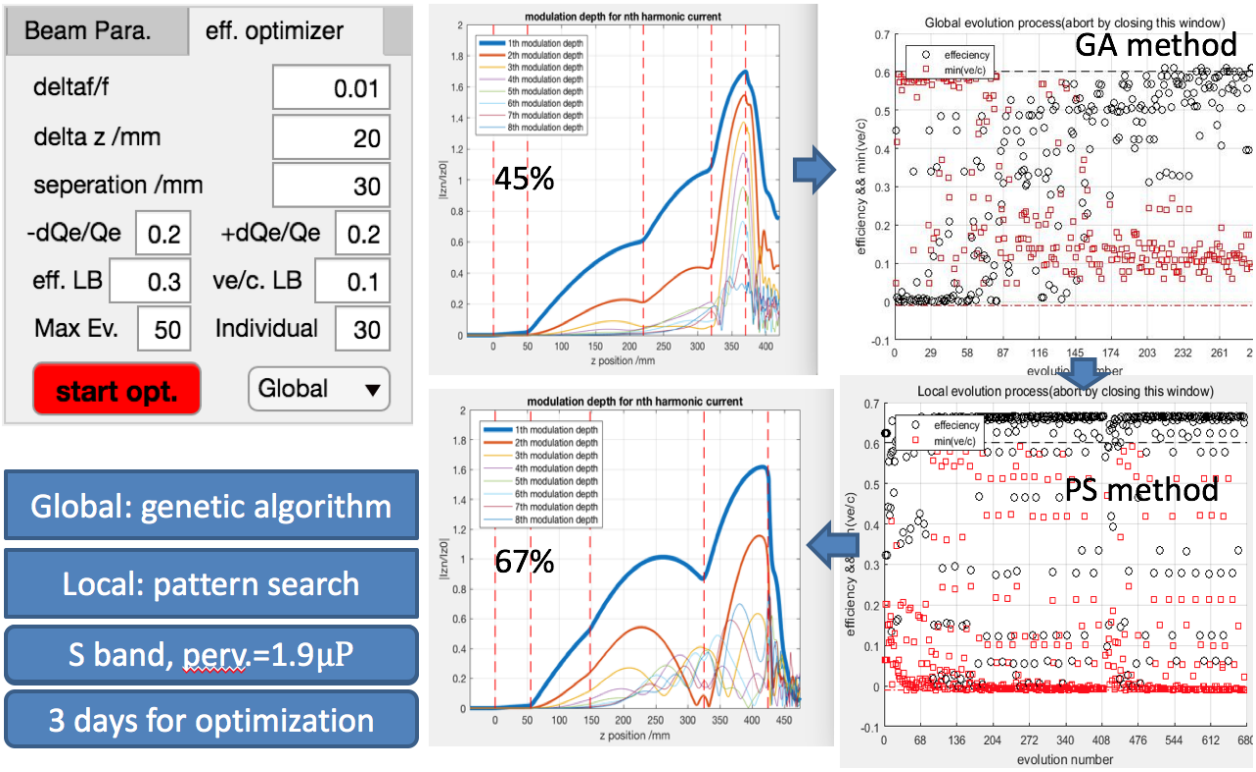
8. KlyC internal optimizer module.

The internal KlyC optimizer module supports Global and Local optimization routines, which are targeted to maximize the RF power production efficiency. The variable parameters are the cavities frequencies tunings, the cavities positions and the external Q factor of the output cavity. To operate optimizer, however, it is recommended that initial klystron design shall be done manually to the extent, when the user decide that the design is already 'good enough'.
The global optimizer uses a large group of individuals to be evaluated, which is rather time consuming. In this method, each new generation is generated by its parental generation through selection, crossover and mutation operations to ensure the improvement of fitness and diversity. The settings for Global/Local optimization shall defined in the efficiency optimizer window:



First, the user has to specify the frequency and position variations boundaries (lines 1 and 2). Next, the cavity 'separation/mm' is used to avoid the situation when neighbor cavities come closer than this specified value (line 3). The parameters window to modify the external Q factor can be chosen to be asymmetric (line 4). The tube layout for every case in optimization will be saved (one by one) into project_name**_opt**.txt file if the simulated efficiency **and**

the minimal velocity of the electrons in the output cavity area have exceeded the specified values of eff. LB and ve/c LB (line 5).
To select between the two regimes, the user should use the bottom right switch (line 6). For the **Local optimizer** the only one case to start is needed, therefore, the population size (Individual) is not used for this optimizer. Without going into details, the **Max Ev**(olution) shall be set to be large enough (50), so that the user can control the process and abort it manually by closing the optimizer process window if the saturation becomes obvious. For the **Global optimizer**, we recommend that the 'Individual' value shall be large as well (30) and again to abort simulations at any convenience. In the next example we have used the high perveance S-band tube, which was initially designed in 1D using the 'classical' bunching technique (efficiency 45%). Next, the consequent Global and Local optimizations have been applied. After 3 days of optimization, the final tube has reached the efficiency of 67% and RF circuit layout was converted to be consistent with COM (core oscillation method) type klystrons.



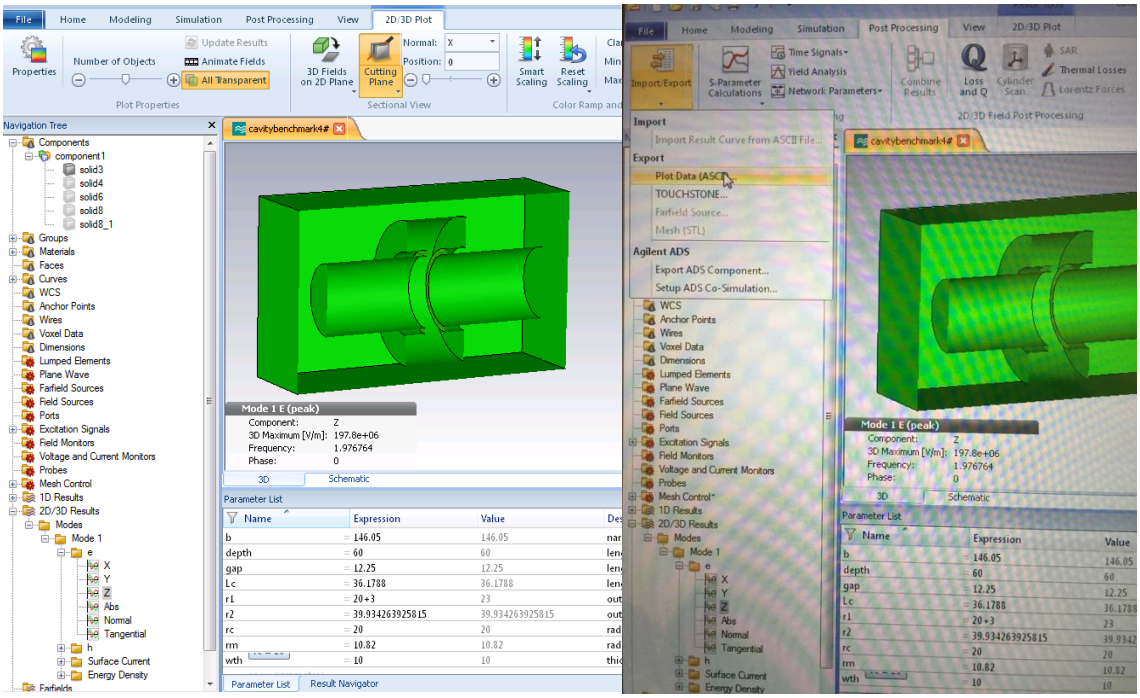
9. The batched jobs

In the case if the parameters sweep, sensitivity analysis or just a few different tubes need to be simulated in an automated manner, one can use the batched job option. Each project (job) has to have its individual klc input file and all of them have to be placed in the same folder. To start such simulations, first open any of the stored klc projects. Next press on the 'RunAll' button. The batched job toggle will turn 'On'. The jobs will be executed one by one following the files names order. The simulations status is indicated by the progress meter on the instrumentation panel. To interrupt the process one need to switch the toggle to its 'Off' position and the simulations will be aborted when the running case is finished. The short summary of batch simulations will be saved as 'txt' file, where some basic simulation results will be ready for comparison. For each individual simulation, the results can also be saved if 'txt output' box is checked.

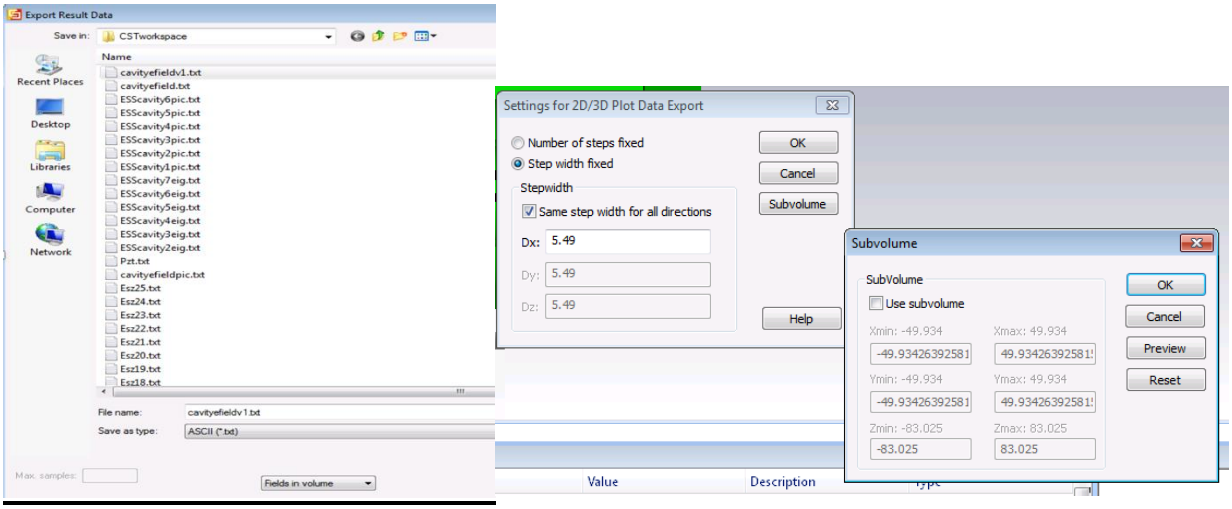
Appendix I. Field imported from other eigen solvers

Preparing data from CST:

1. Z direction should be the longitudinal direction and the gap center of the cavity shall be located at (0,0,0). The cavity shall be introduced as an entire 3D object. No symmetry planes shall be used.



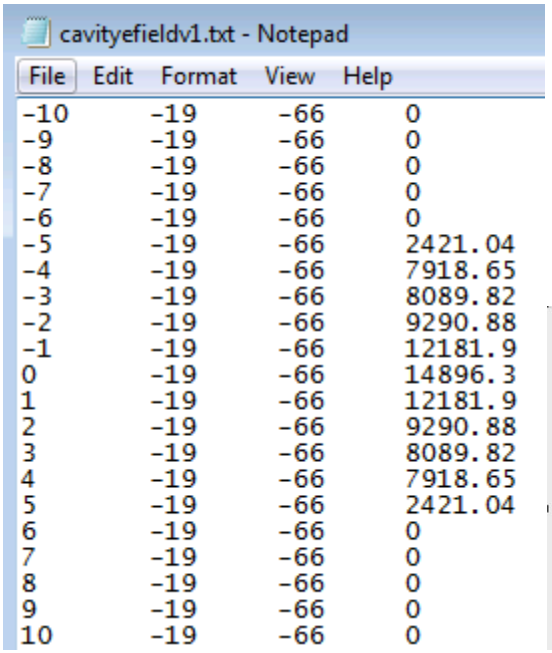
2. After the simulation is finished, plot field distribution for the selected mode.
3. Export plot data using Plot Data Export module

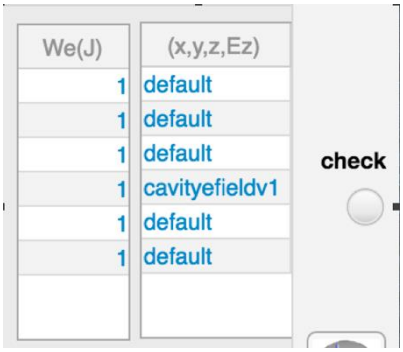


- Choose the name to save to the txt file. Choose the “Field in volume” at the bottom line.
- Choose the region (cubic sub-volume) and output precision (plot mesh) before pressing OK.
- Choose the name to save the txt file. (cavityefieldv1 in this example)

x [mm]	y [mm]	z [mm]	ExRe [V/m]	EyRe [V/m]	EzRe [V/m]	ExIm [V/m]	EyIm [V/m]	EzIm [V/m]
-20	-20	-66	0	0	0	0	0	0
-19	-20	-66	0	0	0	0	0	0
-18	-20	-66	0	0	0	0	0	0
-17	-20	-66	0	0	0	0	0	0
-16	-20	-66	0	0	0	0	0	0
-15	-20	-66	0	0	0	0	0	0
-14	-20	-66	0	0	0	0	0	0
-13	-20	-66	0	0	0	0	0	0

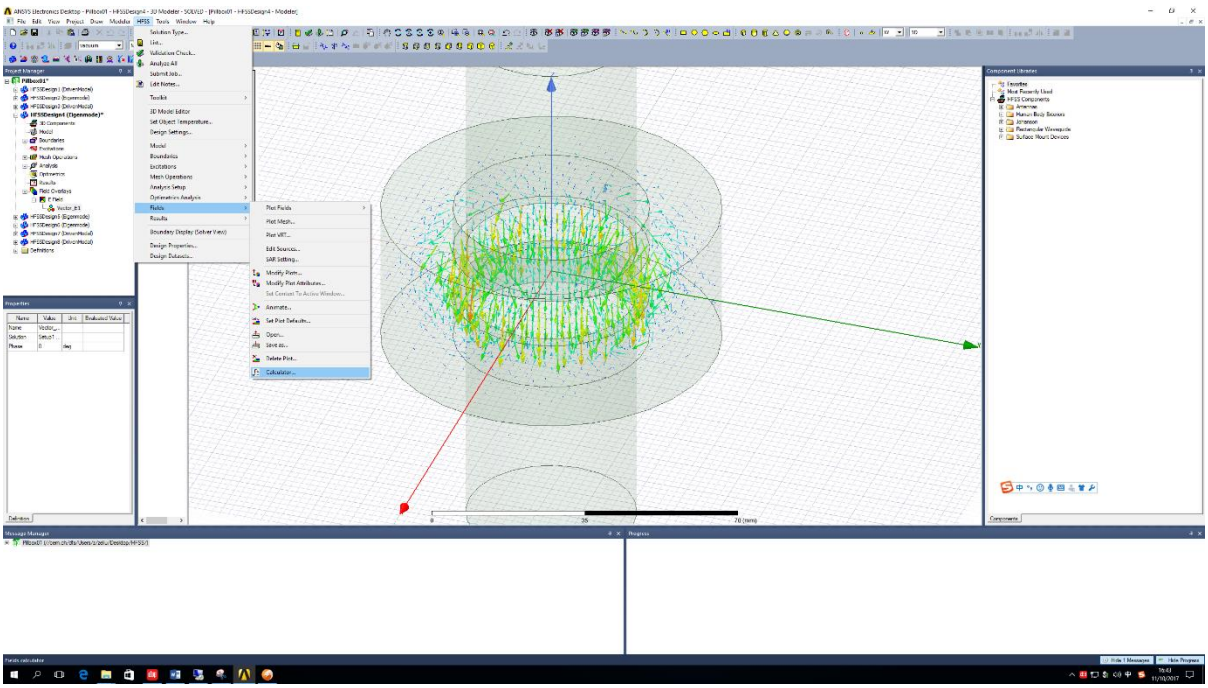
The generated data file (see above) shall be modified to be recognized by KlyC:
1. Delete the text header.
2. Remove the columns 4,5,7,8 and 9, so that column 6 will become column 4 (do it in Excel for example). The processed file shall be save into the folder where the project is located.
In the CST eigenmode solver, the stored energy for any resonant mode is normalized to 1J by default. If one will use some other method to generate filed distribution, the stored energy of resonant shall be calculated.
Put the name of the text file (without extension) with modified filed distribution in the last column of the cavities parameter table (x,y,z,Ez) at a position of selected cavity and specify the value of stored energy (in joules) in the We(J) column. Run the 'update cavity' to see if the import was successful and KlyC has calculated R/Q and M of the cavity. Use the value of Qin simulated in the CST in the cavity parameters table.



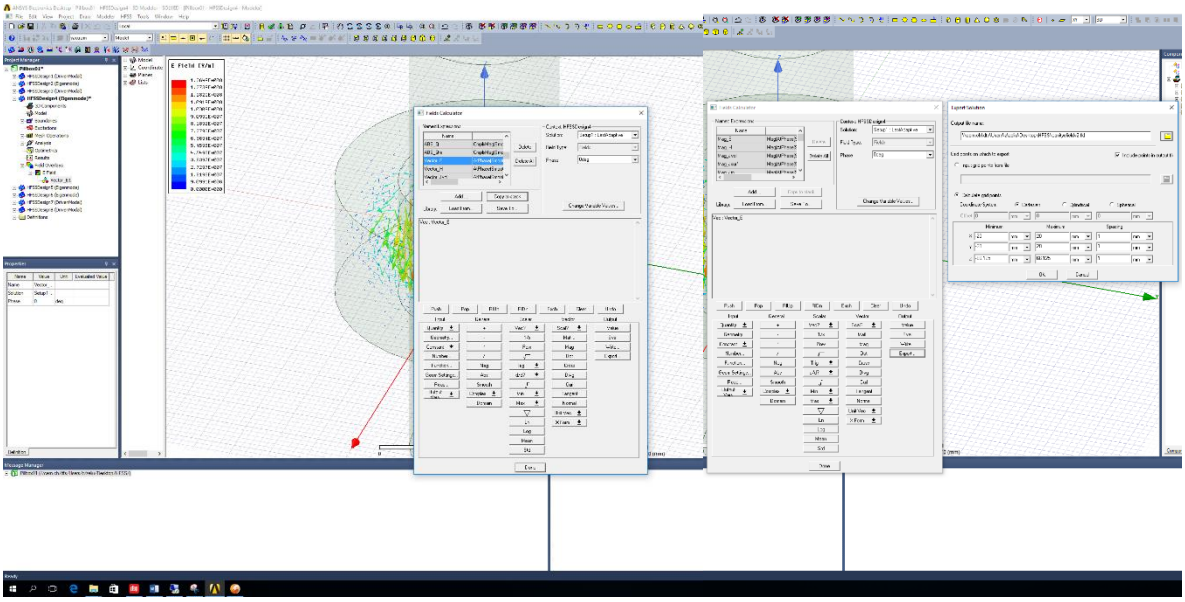


Preparing data from HFSS

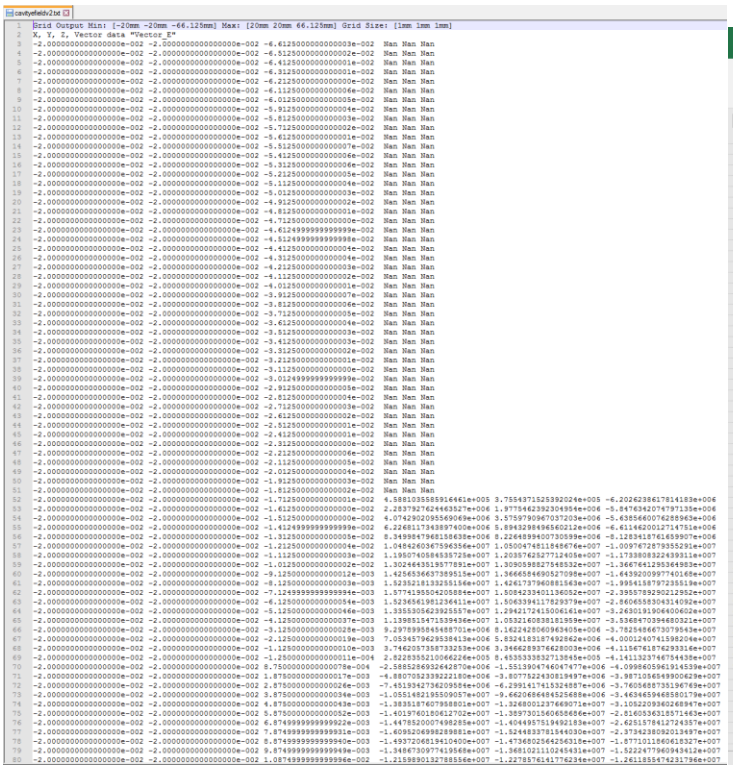
1. Generate the volume E-field plot of the chosen mode.



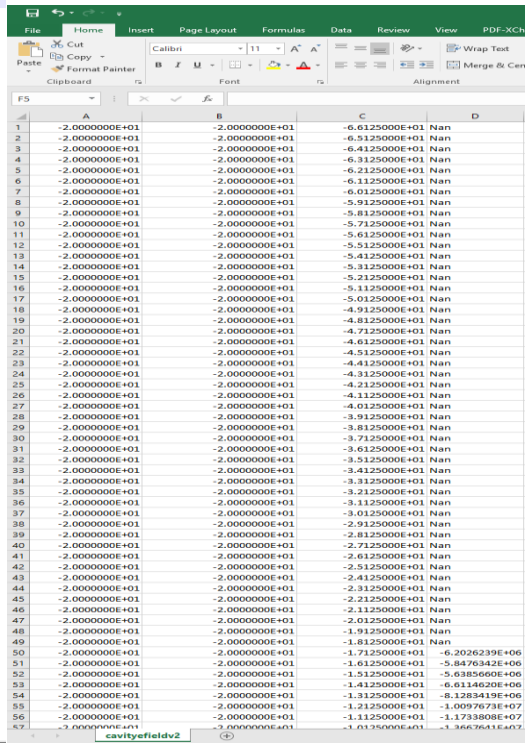
2. Choose the calculator in the post-processing menu.



2. Vector_E shall be copied to the stack before activating Export button.
3. Export field data by selecting a specific cubic region as shown above.
4. Change the type of exported data file to .txt and open it:



Raw Data



Data processed

Note, that in HFSS that the geometry is normally specified in m. Next:

1) Delete the text header (the first 2 rows).
2) Delete columns 4 and 5, so that Ez(V/m) will become column 4..
3) The data in the first 3 columns shall be multiplied by 1000 to convert m into mm.

In the HFSS eigenmode solver, the stored energy for any resonant mode is normalized to 1J by default. Next, follow the same sequence as it was explained above for the CST case.