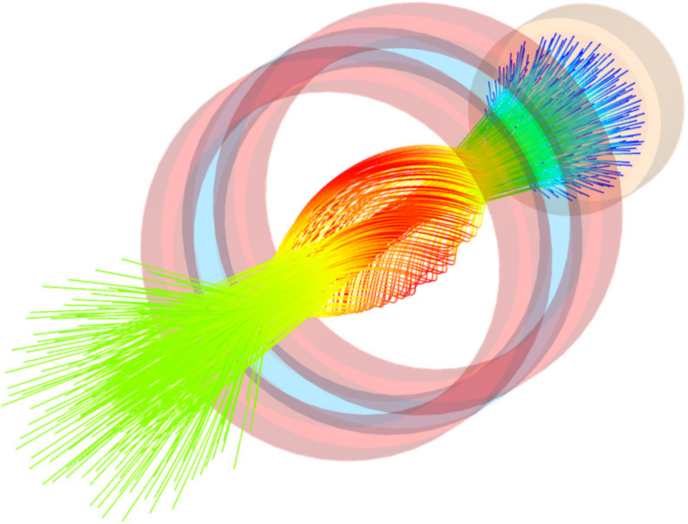
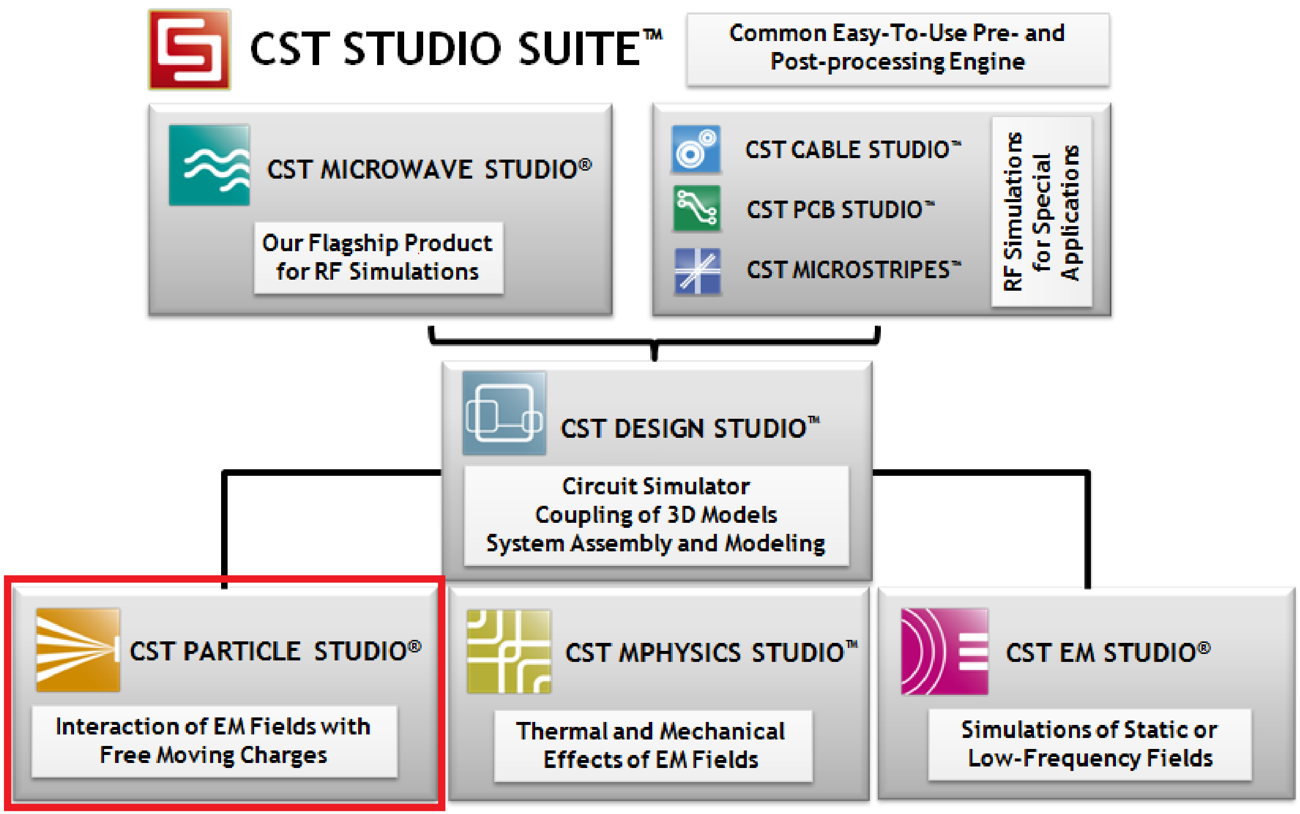
Latest Developments in 3D Charged Particle Simulations

Felix Wolfheimer, CST AG



CST STUDIO SUITE - Overview



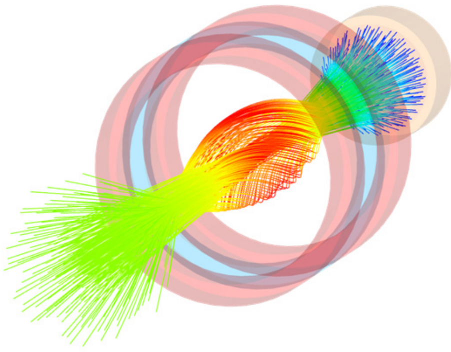
CST PARTICLE STUDIO

Trk	**Tracking**	Solver for particles in static fields including space charge or in harmonic fields excluding space charge.
Pic	Particle In Cell	Self-consistent transient field and particle solver including full space charge effects at all frequencies.
WAK	Wakefield	Transient solver with special beam excitation (predefined fixed straight beam path)

Tracking Algorithm

Workflow

1. Calculate electro- and magnetostatic fields.
2. Move particles according to the previously calculated force. → Trajectories
3. Adjust trajectories/fields according to space-charge (gun iteration).



$$\frac{d}{dt}(m\vec{v}) = q(\vec{E} + \vec{v} \times \vec{B})$$

Velocity update

$$m^{n+1}\vec{v}^{n+1} = m^{n}\vec{v}^{n} + q\Delta t\left(\vec{E}^{n+1/2} + \vec{v}^{n+1} \times \vec{B}^{n+1/2}\right)$$

$$\frac{d\vec{r}}{dt} = \vec{v}$$

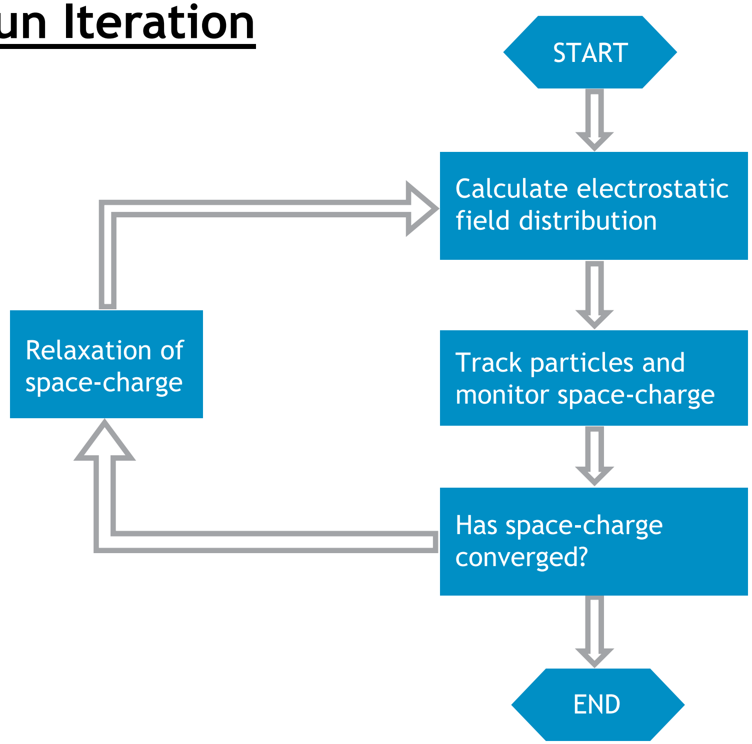
Position update

$$\vec{r}^{\,n+3/2} = \vec{r}^{\,n+1/2} + \Delta t\,\vec{v}^{\,n+1}$$

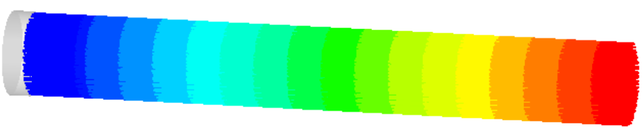
Leap Frog Scheme

Gun Iteration - Space Charge Effect

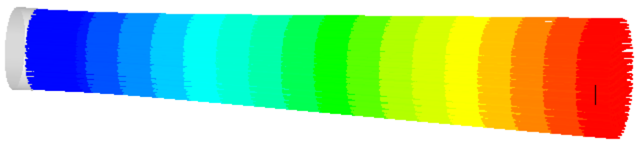
Gun Iteration



Without gun iteration:

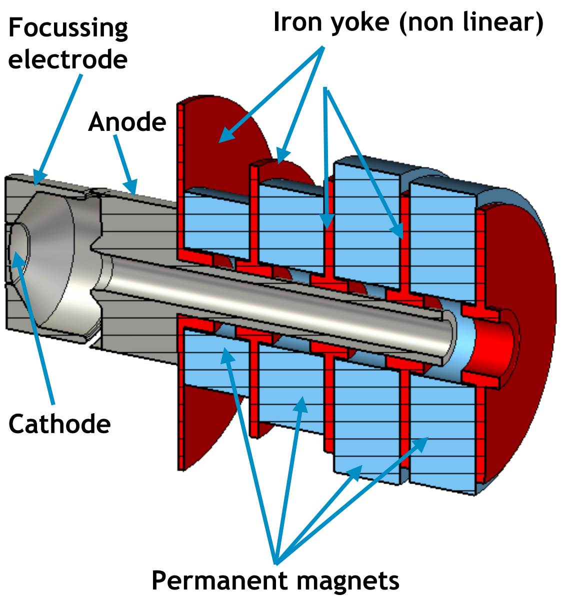


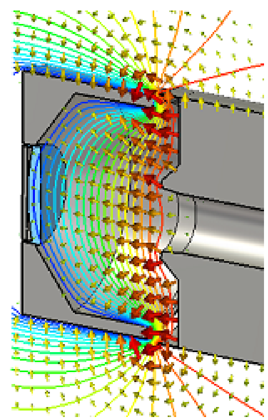
With gun iteration:



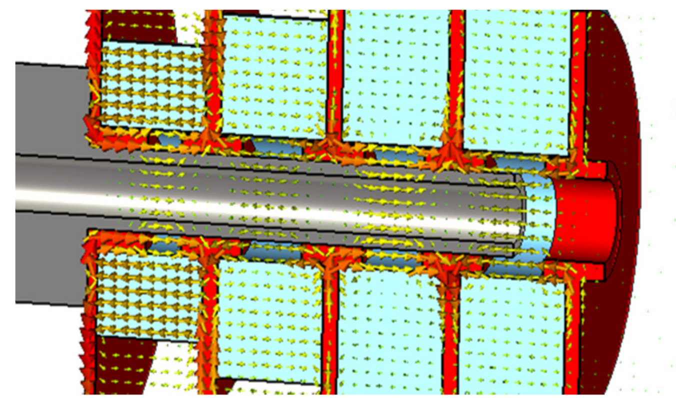
Tracking Solver - Typical Application (I)

Electron Gun





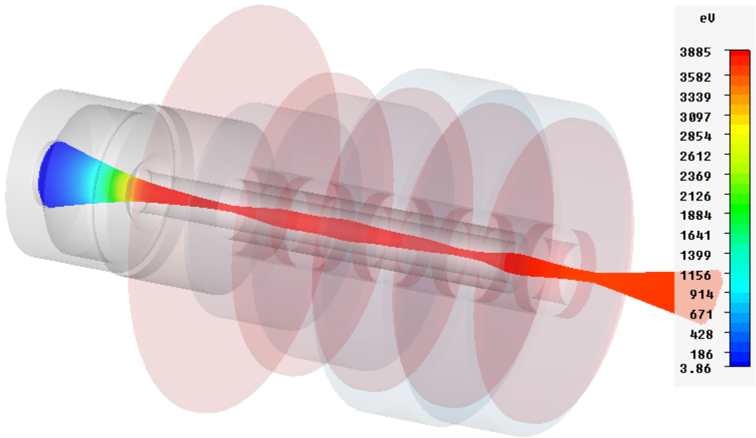
E-static field

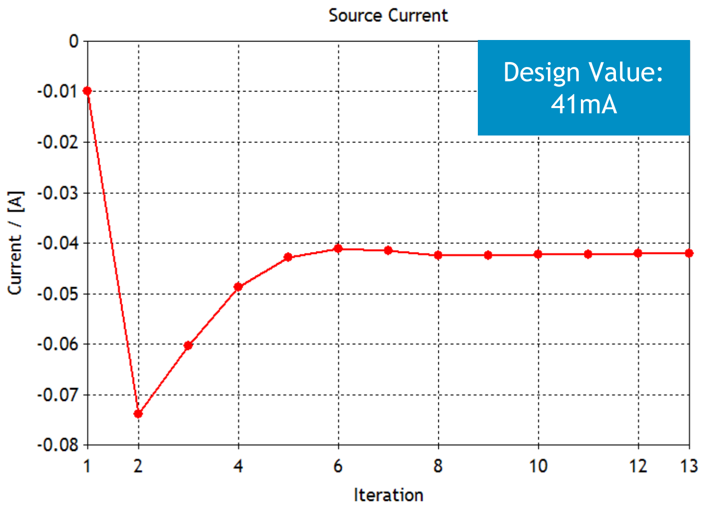


M-static field

Tracking Solver - Typical Application (II)

Electron Gun





Space charge effect is included via gun iteration and space charge limited emission.

CST PARTICLE STUDIO

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Pic	**Particle In Cell**	Self-consistent transient field and particle solver including full space charge effects at all frequencies.
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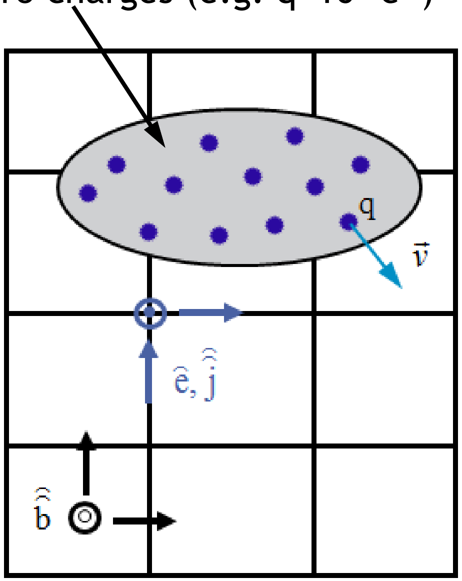
Particle in Cell (PIC) Algorithm

Self-consistent modeling of a collision free plasma.

Macro charges (e.g. q=10^6 e^-)



Relativistic equation of motion

$$\frac{d}{dt}(m\vec{v}) = q(\vec{E} + \vec{v} \times \vec{B})$$

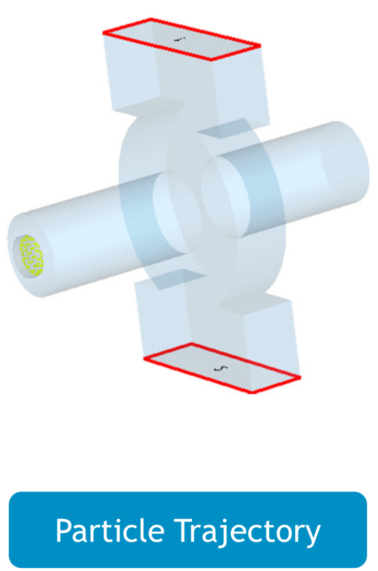
$$\frac{\mathrm{d}\vec{r}}{\mathrm{d}t} = \vec{v}$$

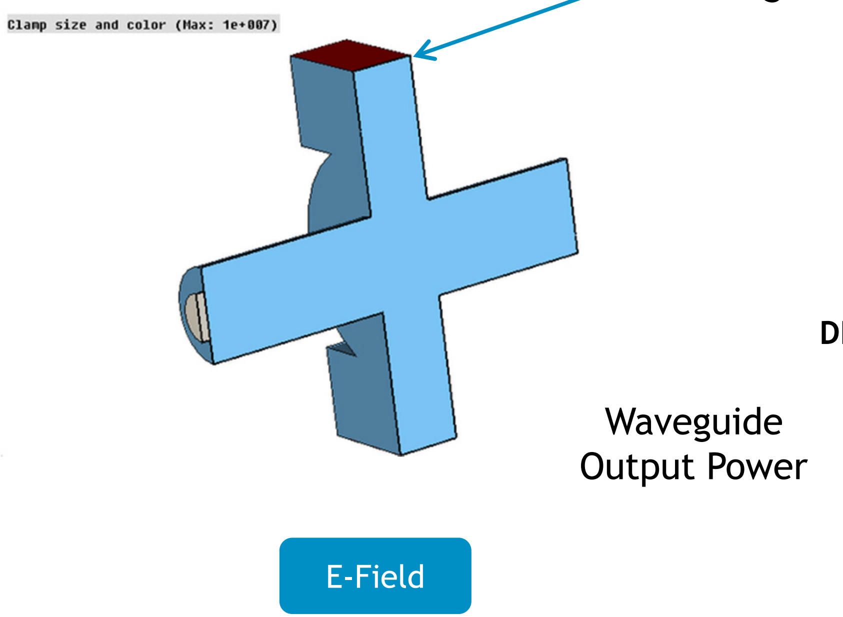
Current caused by particle motion acts as source in Maxwell's equations.

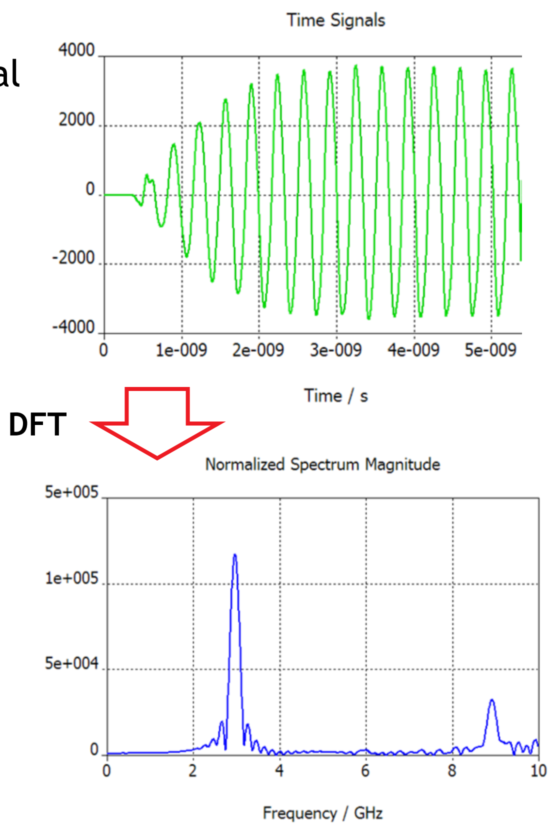
$$\mathrm{curl}\,\vec{H} = \frac{\partial \vec{D}}{\partial t} + \vec{J}; \qquad \mathrm{div}\vec{J} = -\frac{\partial \rho}{\partial t}$$

A priori charge conserving algorithm.

PIC Solver - Typical Applications (I)

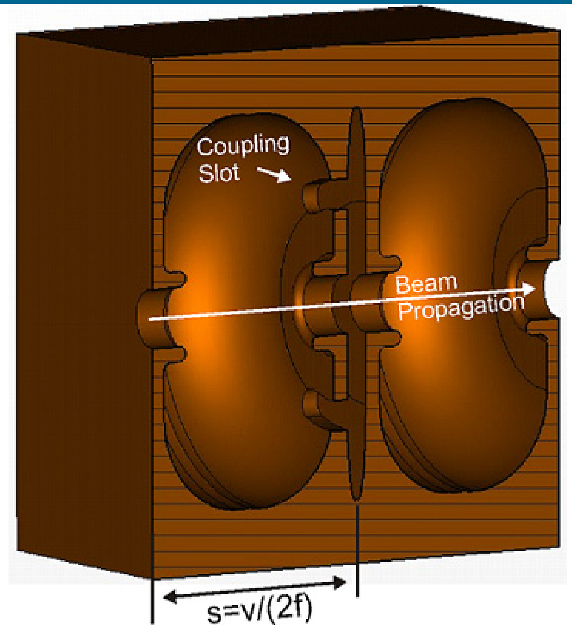


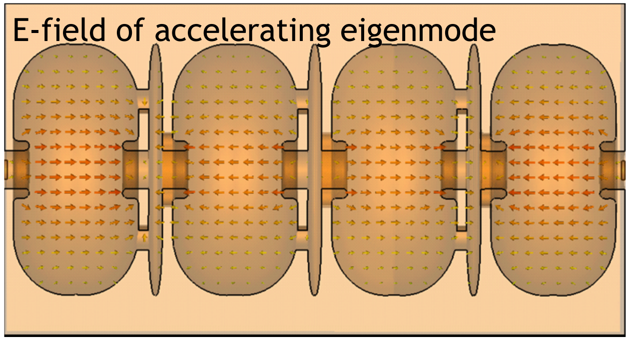


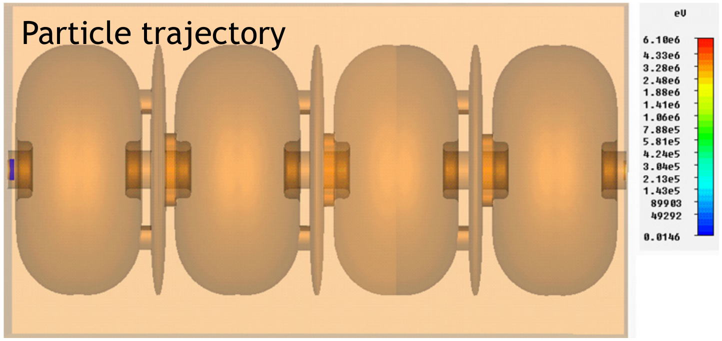


PIC Solver - Typical Applications (II)

C-Band Linear Accelerator

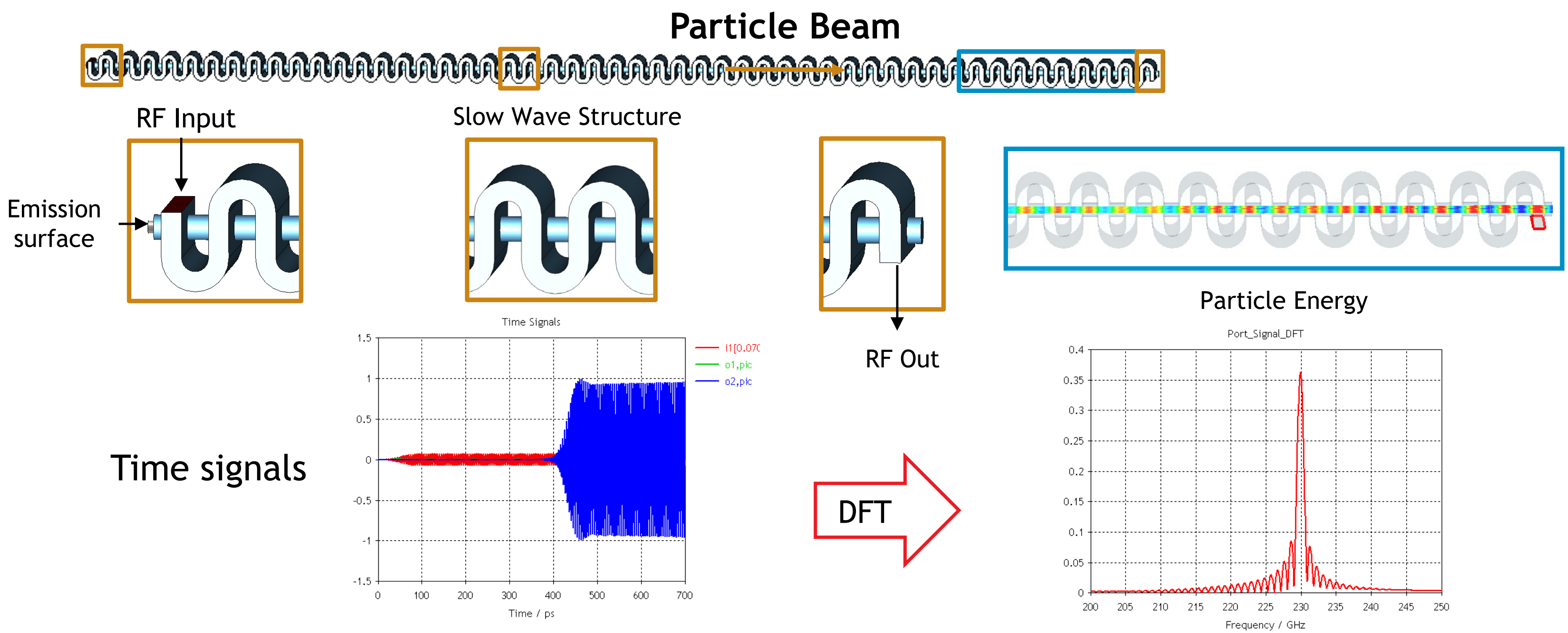






[1] Design, simulation and measurement conducted by M. Ruf, K. Thurn and L.-P. Schmidt at Chair for High Frequency Technology, University of Erlangen-Nuremberg

PIC Solver - Typical Applications (III)



[1] R. Zheng and X. Chen, "Design and 3-D Simulation of Microfabricated Folded Waveguide for a 220GHz Broadband Travelling-Wave Tube Application", Proceedings of the IVEC 2009, Rome, Italy, April 28-30, pp. 135-136, 2009.

CST PARTICLE STUDIO

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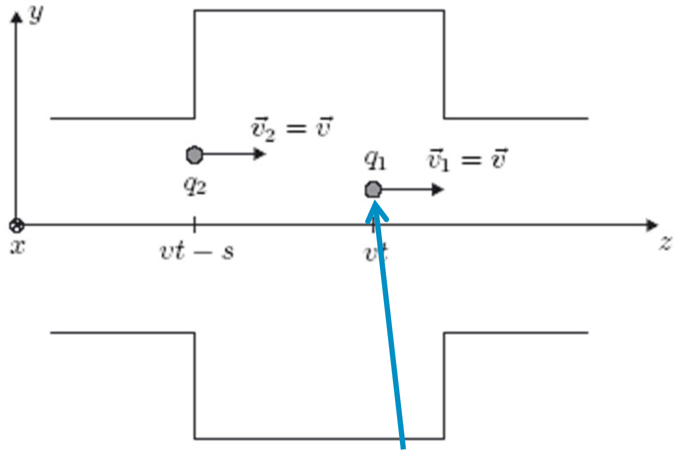
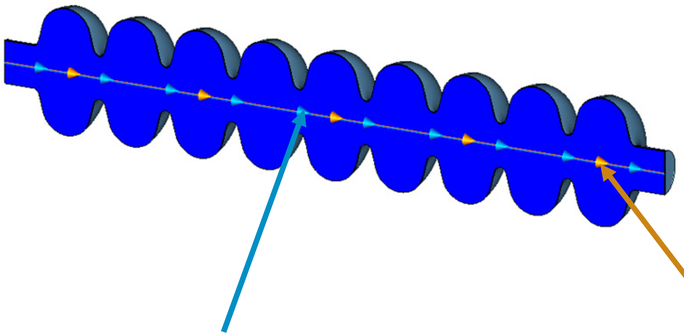
WAK	**Wakefield**	Transient solver with special beam excitation (predefined fixed straight beam path)

Wakefield Solver

The Wakefield solver computes the wake potential:

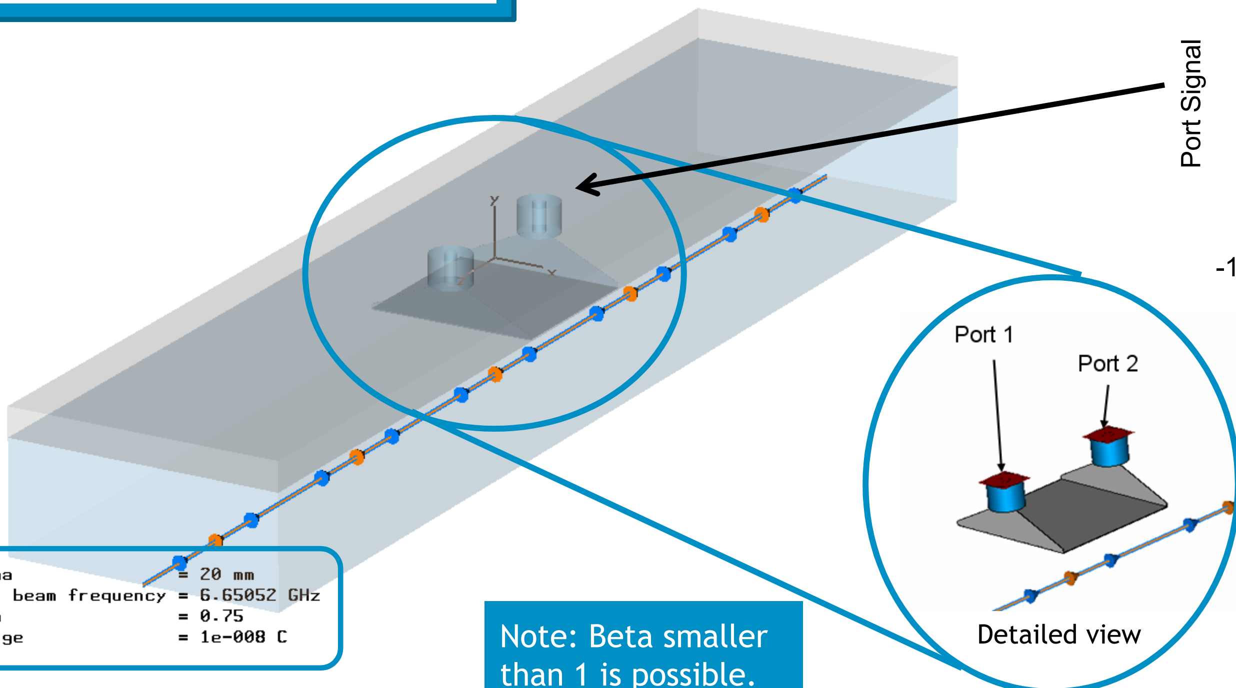
$$\vec{W}(x,y,s) = \frac{1}{q_1}\int_{-\infty}^{\infty}\left(\vec{E}(x,y,z,t=\frac{s+z}{v}) + \vec{v}\times\vec{B}(x,y,z,t=\frac{s+z}{v})\right)dz$$





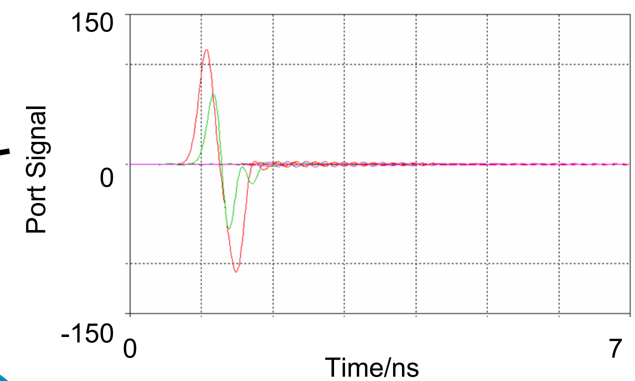
Wakefield Solver - Typical Application

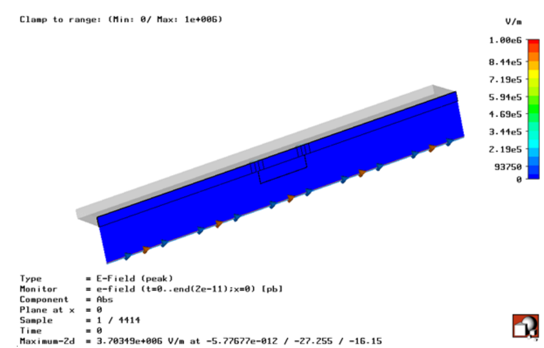
Beam Position Monitor



Sigma	=	20 mm
Max. beam frequency	=	6.65052 GHz
Beta	=	0.75
Charge	=	1e-008 C

Note: Beta smaller than 1 is possible.





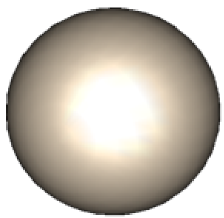
New Features Overview

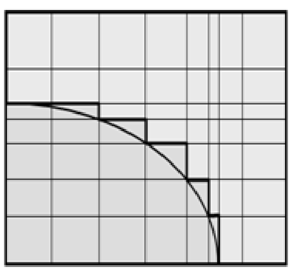
Geometry Handling - Hexahedral Mesh

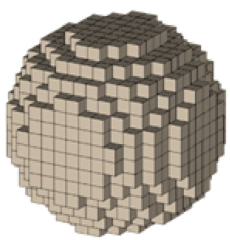
- CST has extended the numerical algorithms with enhanced material approximation techniques.

Continuous material distribution

(object with curved boundaries)

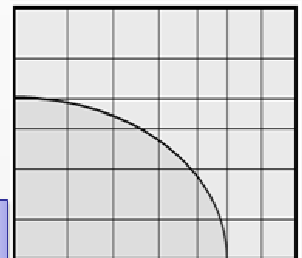


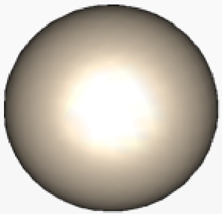




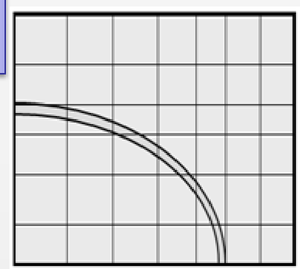
Hexahedral mesh with simple "staircase" approximation

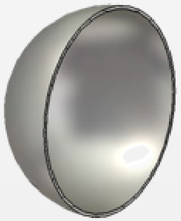
Developed by CST





Hexahedral mesh with PBA material approximation for metallic objects





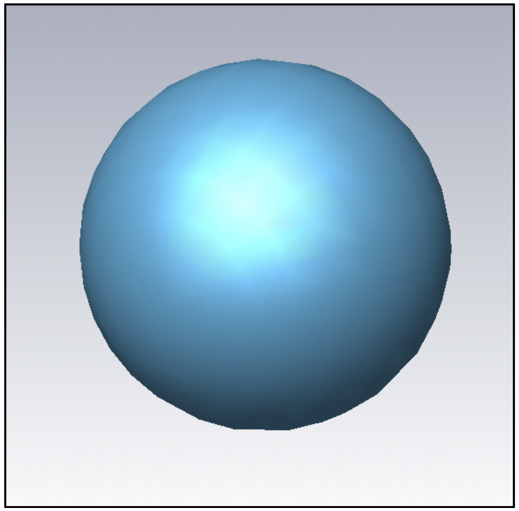
Hexahedral mesh with TST material approximation for metallic objects

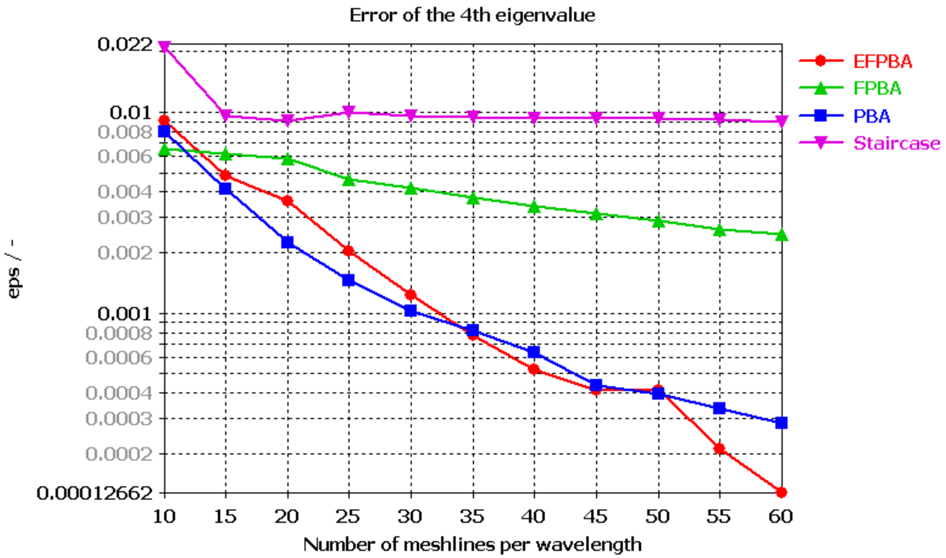
PBA (Perfect Boundary Approximation):
-Very accurate, but relies on valid CAD shapes.

FPBA (Fast PBA):
-Faster than PBA
-Can handle even CAD models with artifacts
-Less accurate as compared to PBA

Geometry Handling - Hexahedral Mesh

EFPBA is now the default algorithm used for solvers based on hexahedral meshes

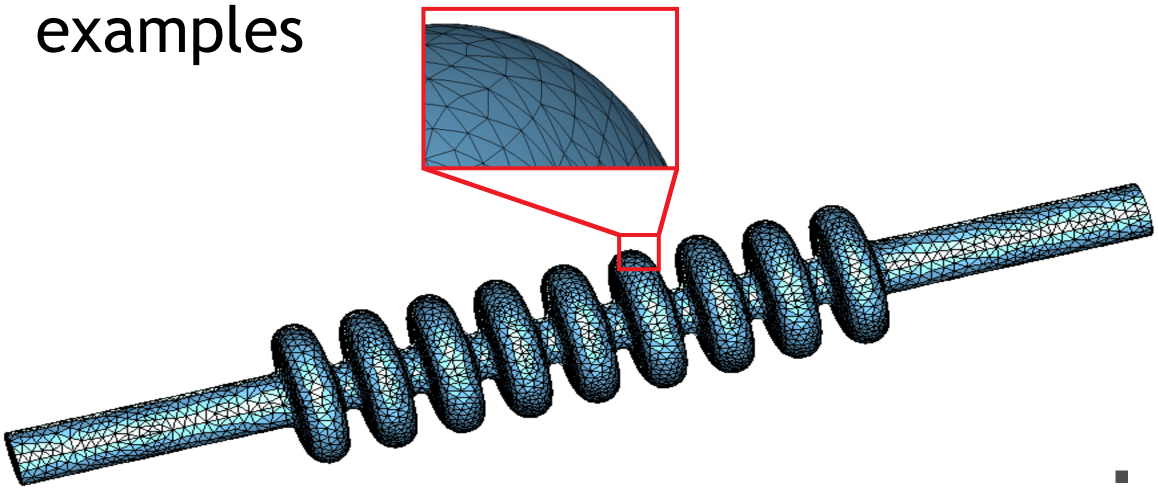


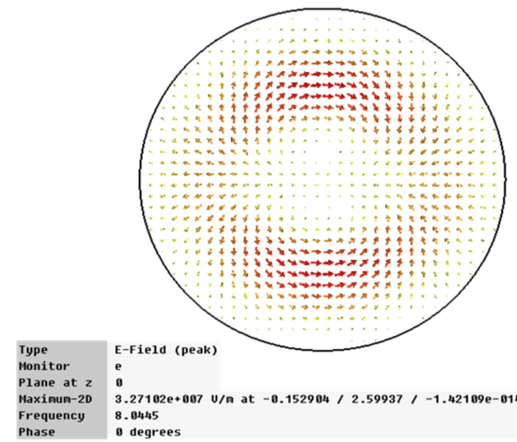


Enhanced FPBA provides both the robustness of FPBA and the accuracy of PBA.

Eigenmode Solver

- **Curved tetrahedral mesh** available (up to 3rd order)
- Improved performance and convergence for many examples

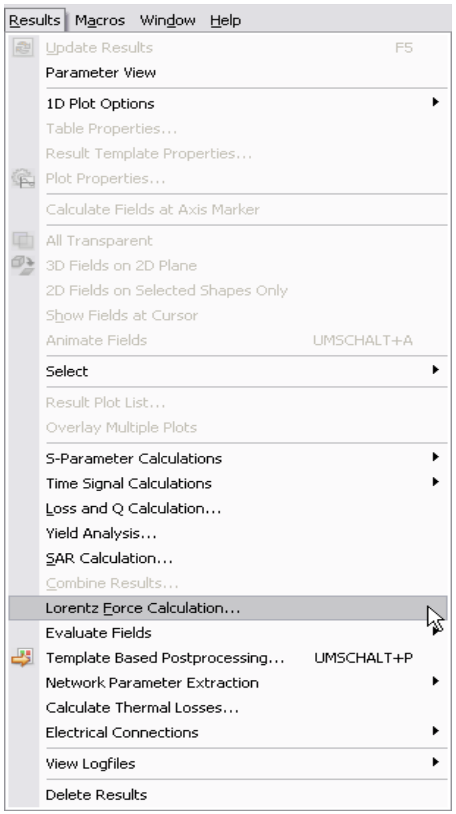


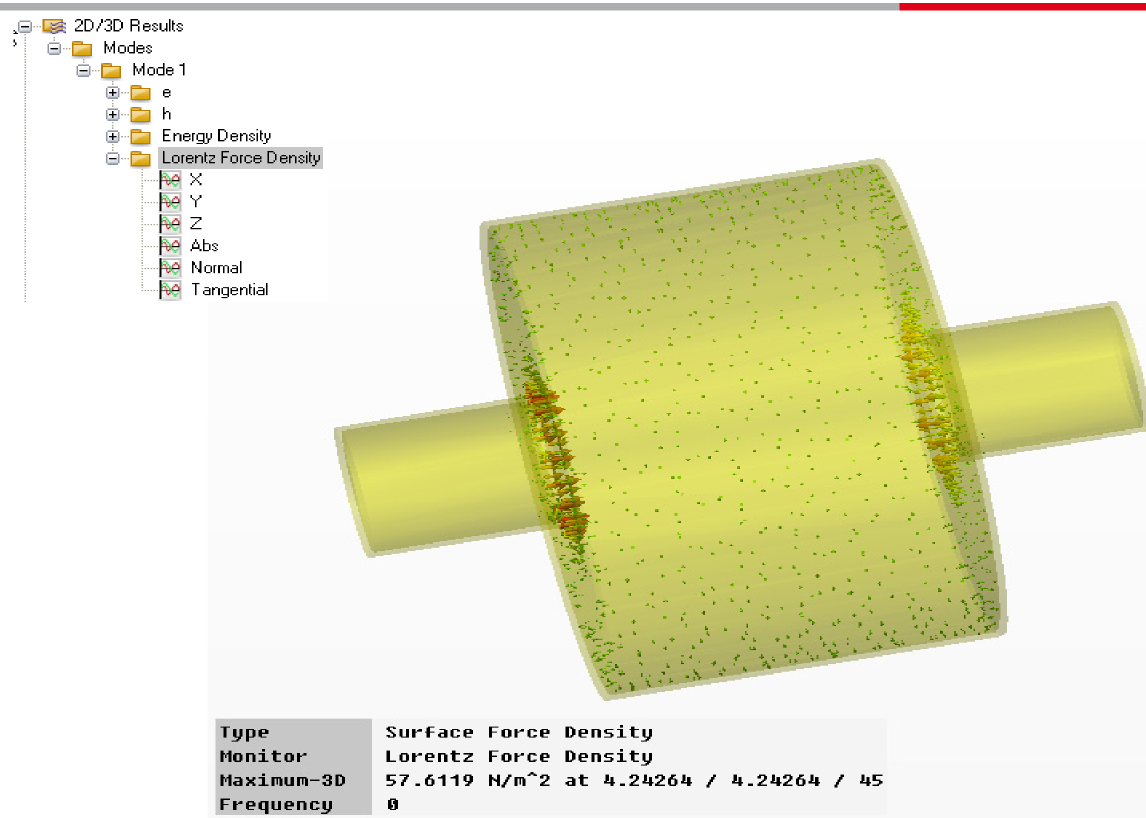


- Tetrahedral mesh: quick convergence, < 2 min to calculate 9 modes

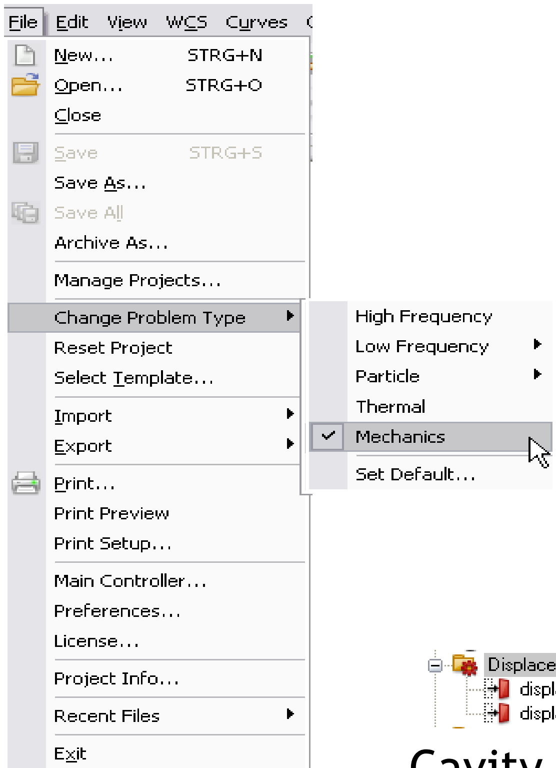
Model courtesy of Lancaster University, Dr. Graeme Burt

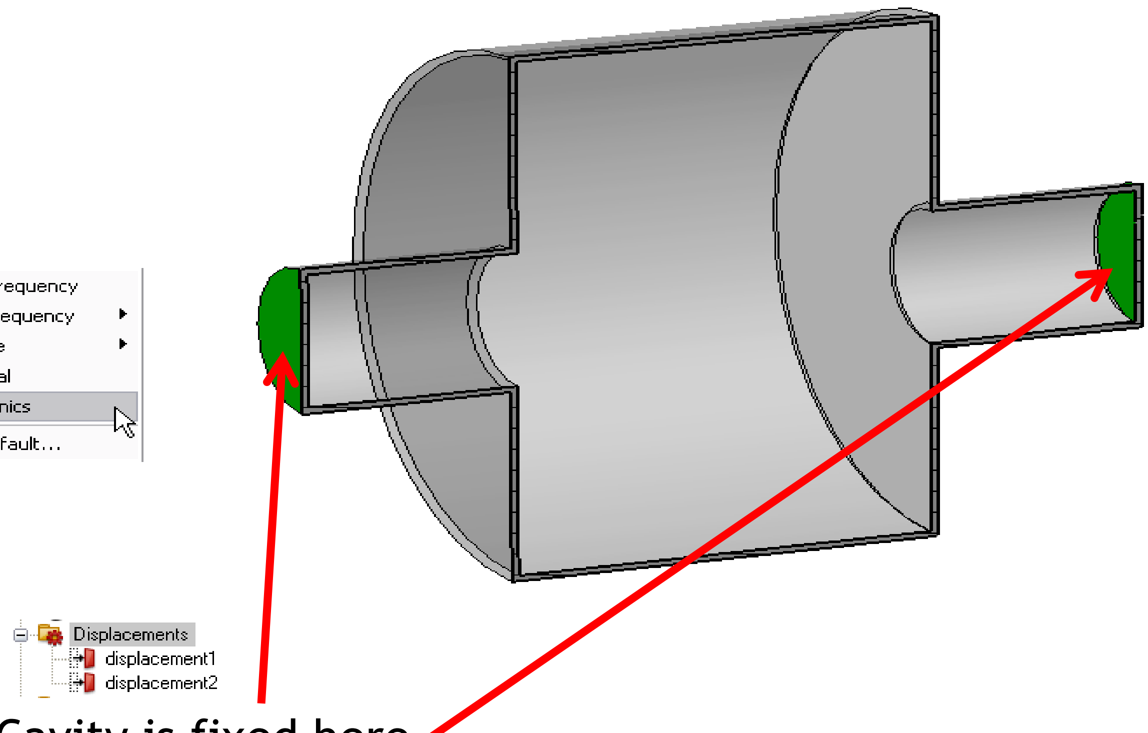
Eigenmode Solver: Lorentz Force Detuning





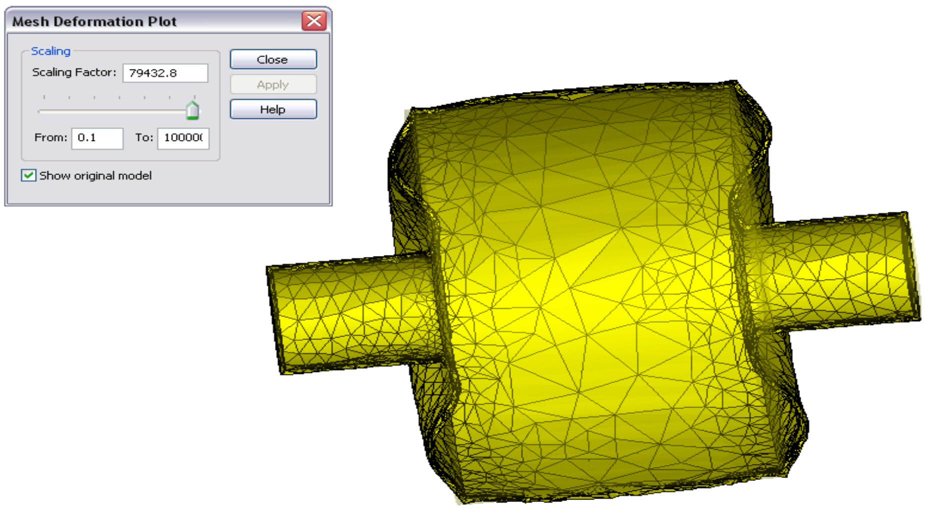
Mechanics: Lorentz Force Detuning





Cavity is fixed here

Deformed Mesh (scaled)



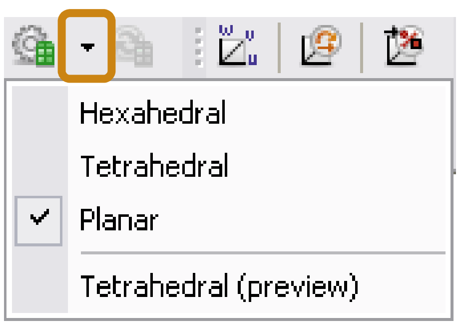
Type	Displacement
Scaling	79432.8
Maximum-3D	4.194e-007 m at 17.1436 / -1.60475 / 15
Frequency	0

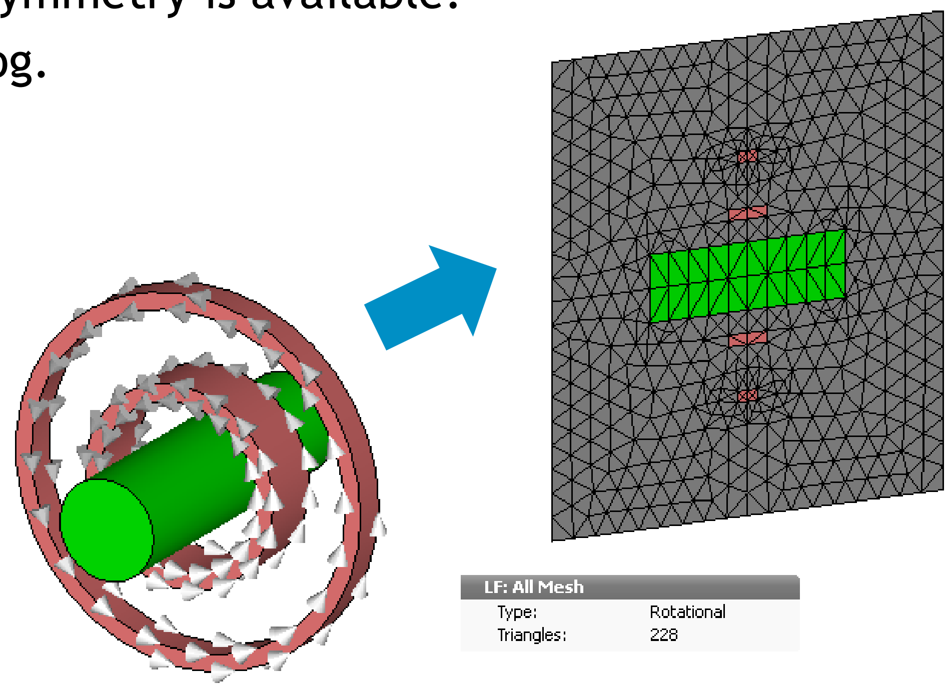
Outlook

- Sensitivity analysis for eigenmode solver to evaluate from Lorentz force.
- Automation with System Assembly and Modeling (SAM) possible.

2D Magnetostatic Solver

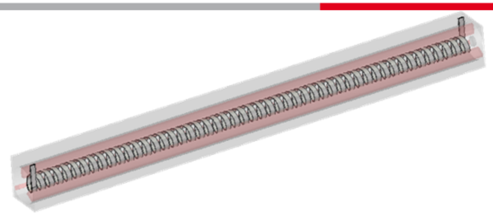
- Rotational and translational symmetry is available.
- Can be selected in mesh dialog.
- Automatic mesh adaption.

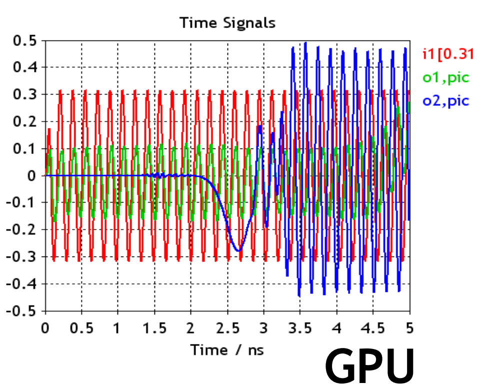


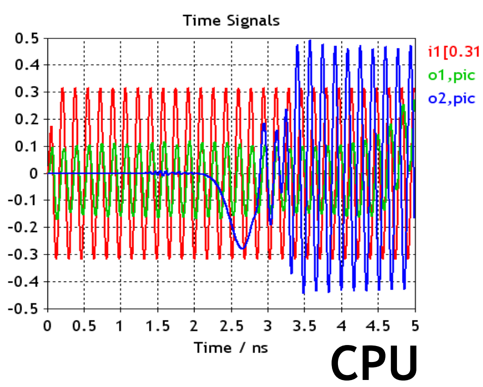


PIC Solver: GPU Computing

Nvidia Tesla 20 cards
are supported





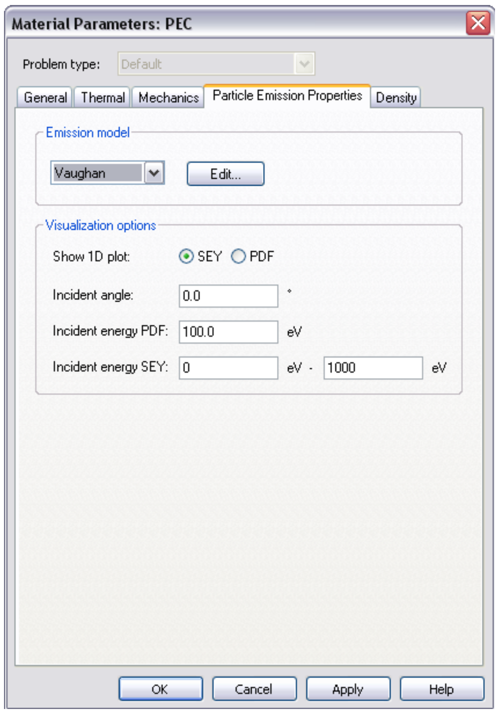


Number of Mesh Cells	1,000,188
Av. Particle Number	7.74e5
Time CPU (Dual Xeon 5620)	1h 14m 44s
Time GPU	12m 25s
Total Speed Up*	6.02
Time Domain Speed Up	6.65

* Matrix calculation & post-processing are not running on GPU

PIC Solver: Secondary Electron Emission Models

New model: Vaughan

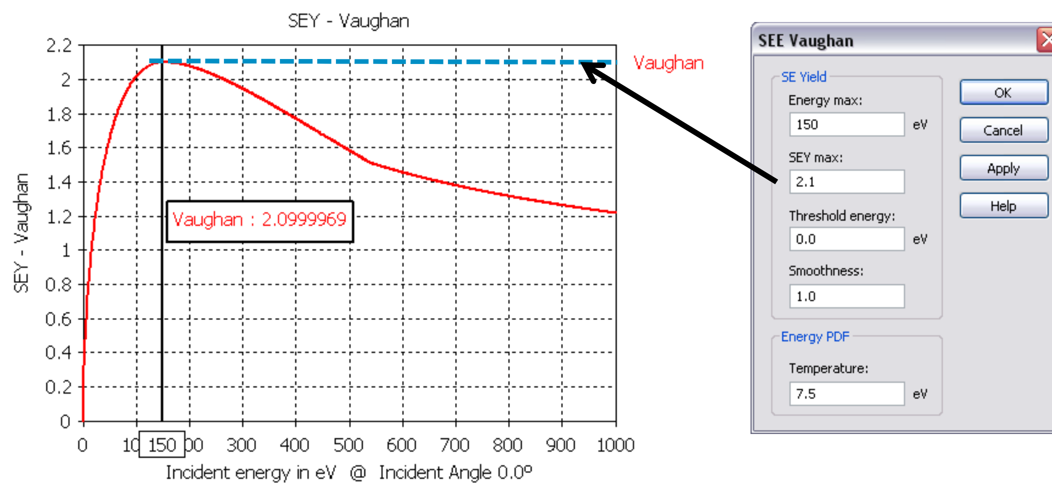


Advantages:

- Only a few parameters to configure

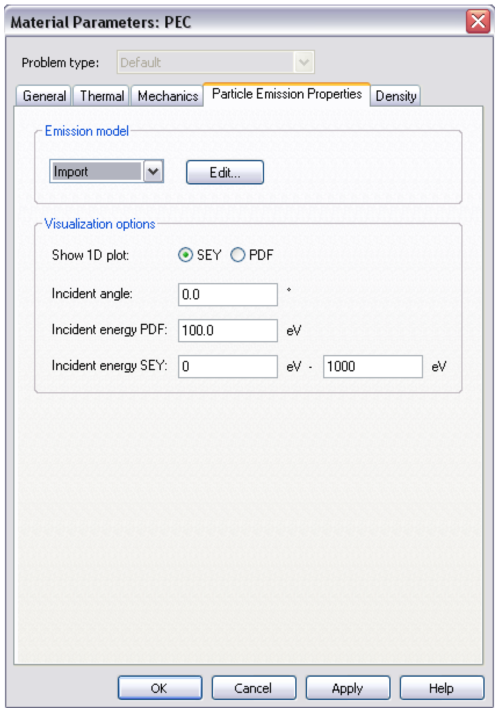
Disadvantage:

- Limited curve shapes
- Only true secondaries
- Not supported on the GPU, yet.



PIC Solver: Secondary Electron Emission Models

New model: Import

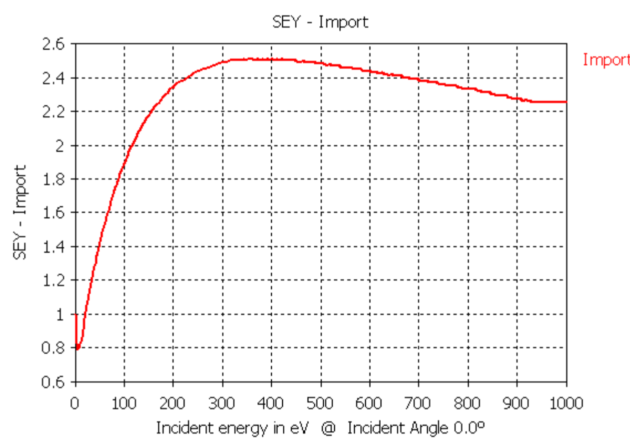


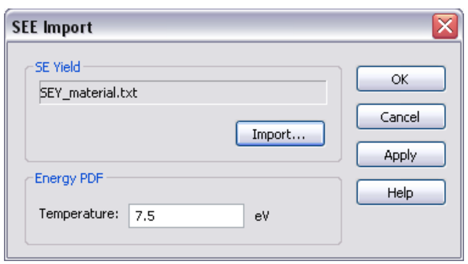
Advantages:

- Easiest definition
- Loading of measurement data possible
- GPU support

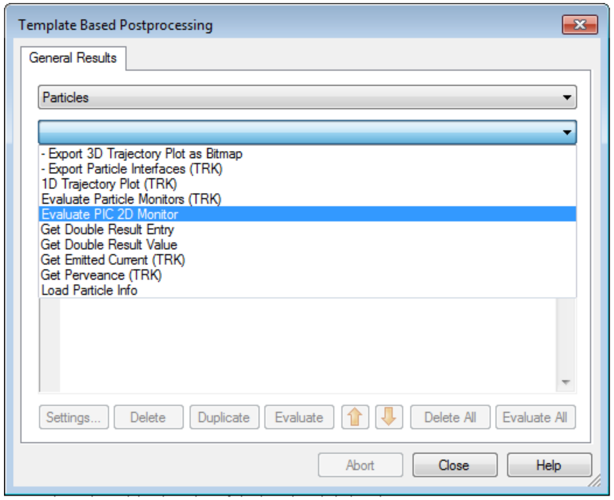
Disadvantage:

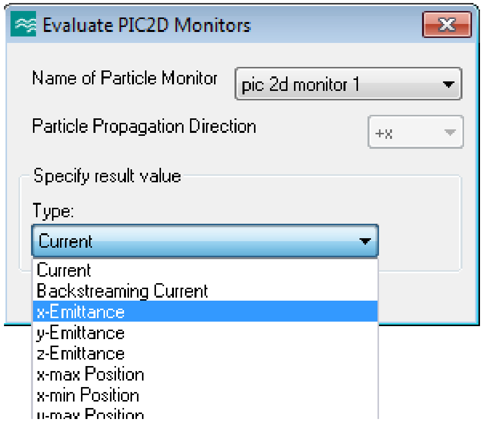
- Only true secondaries





Post Processing - Emittance





Emittance definition used:

$$\epsilon_{x,rms} = \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle x x' \rangle^2}$$

Emittance often used by accelerator people:

$$\epsilon_{n,rms} = \beta \gamma \epsilon_{rms}$$

Any Questions?