Various approaches to electromagnetic field simulations for RF cavities

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Outline

- Cavity modeling in CST MICROWAVE STUDIO®
- Field simulation in time domain
- Field simulation in frequency domain
- Detection of the eigenmodes in the transmission spectrum
- Future work

SPL Cavity Modeling in CST MICROWAVE STUDIO®

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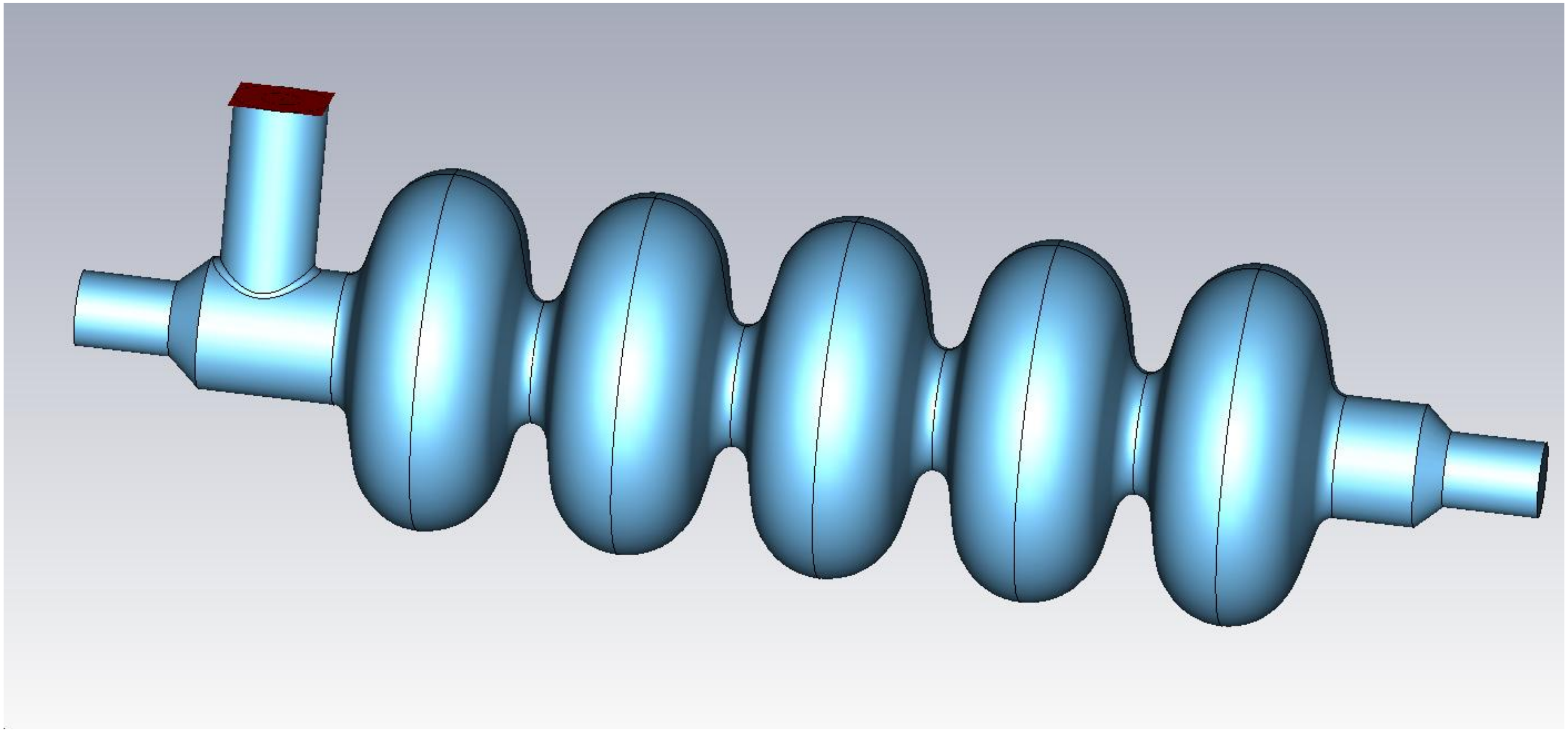
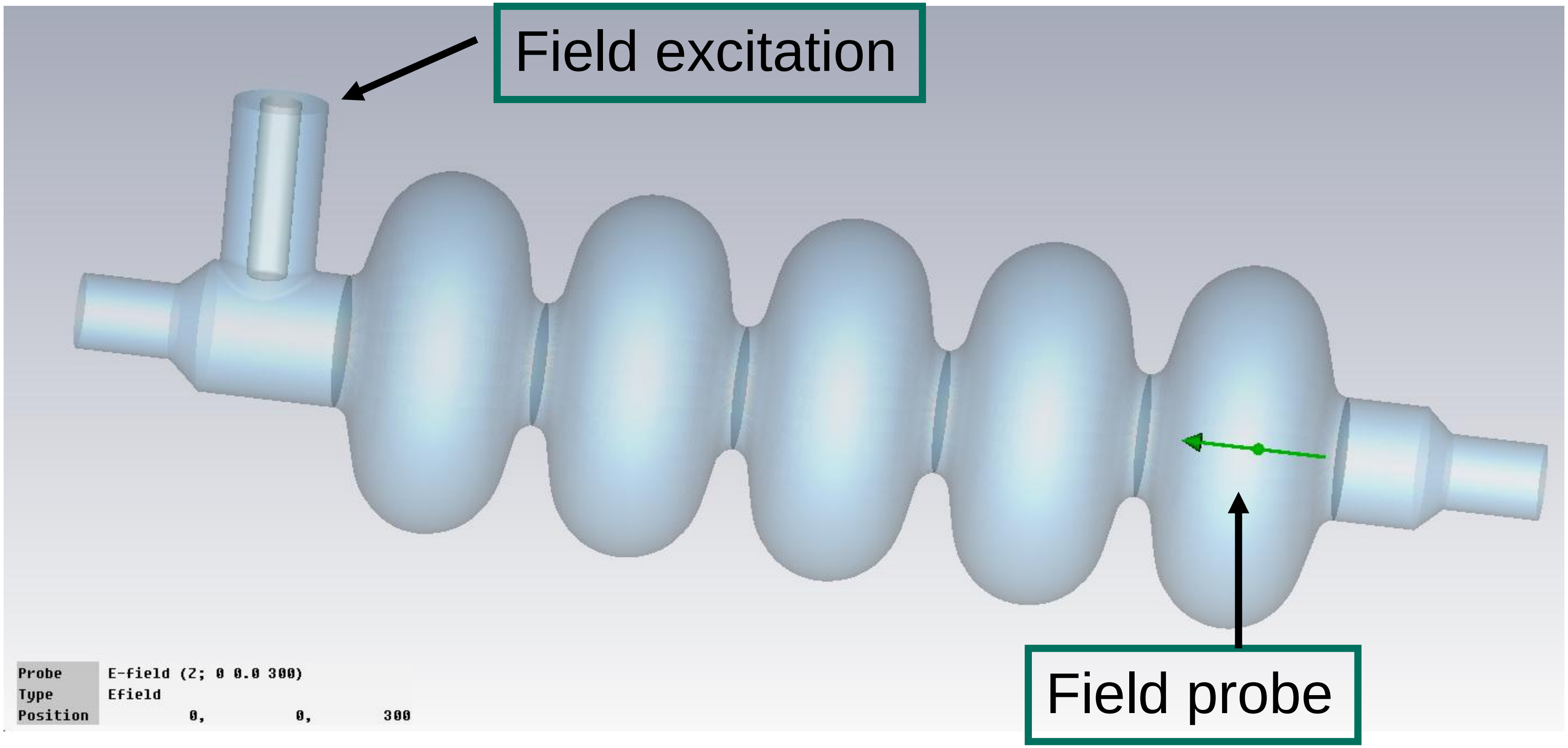


Field Simulation in Time Domain



Field Simulation in Time domain

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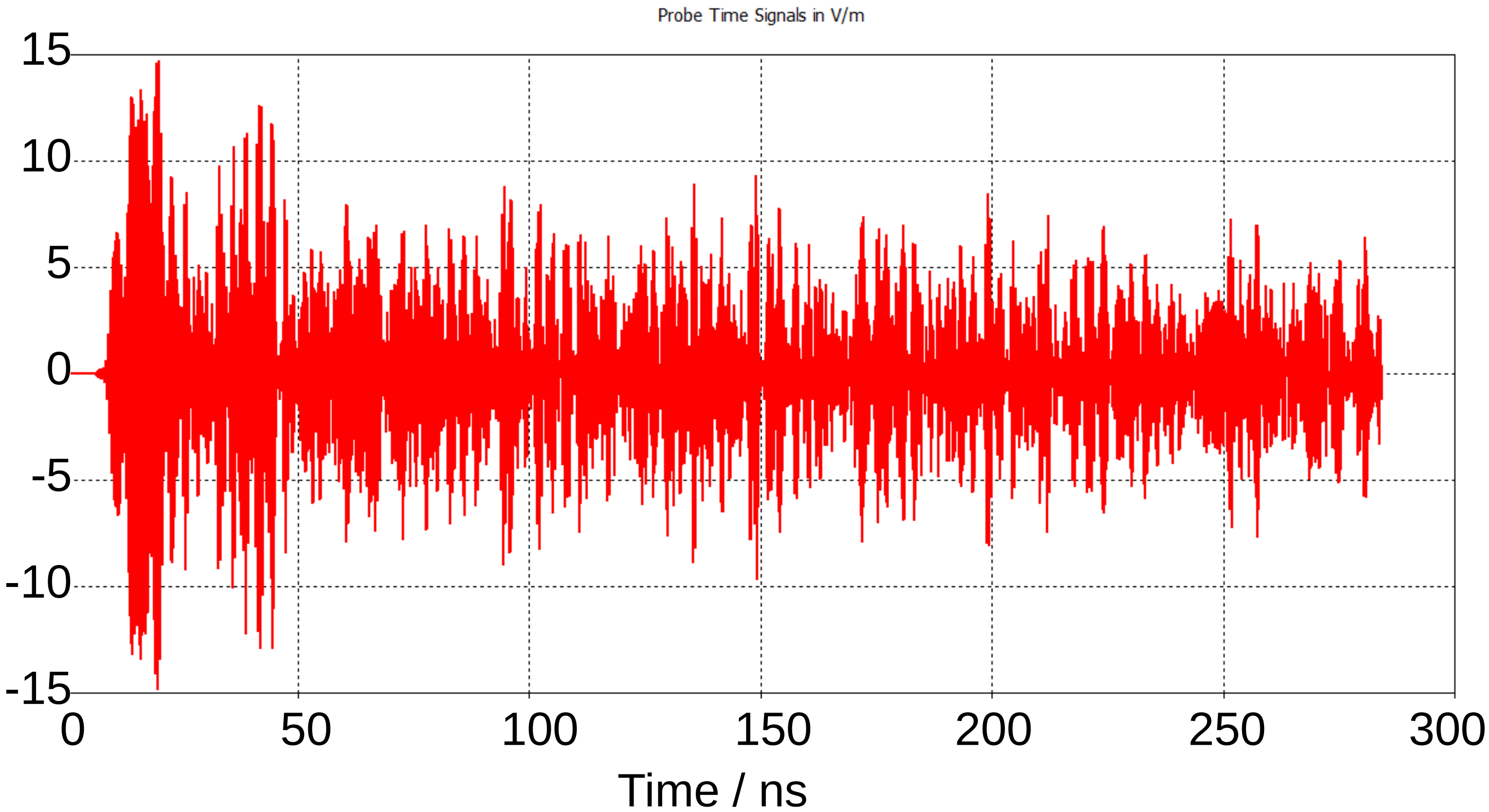
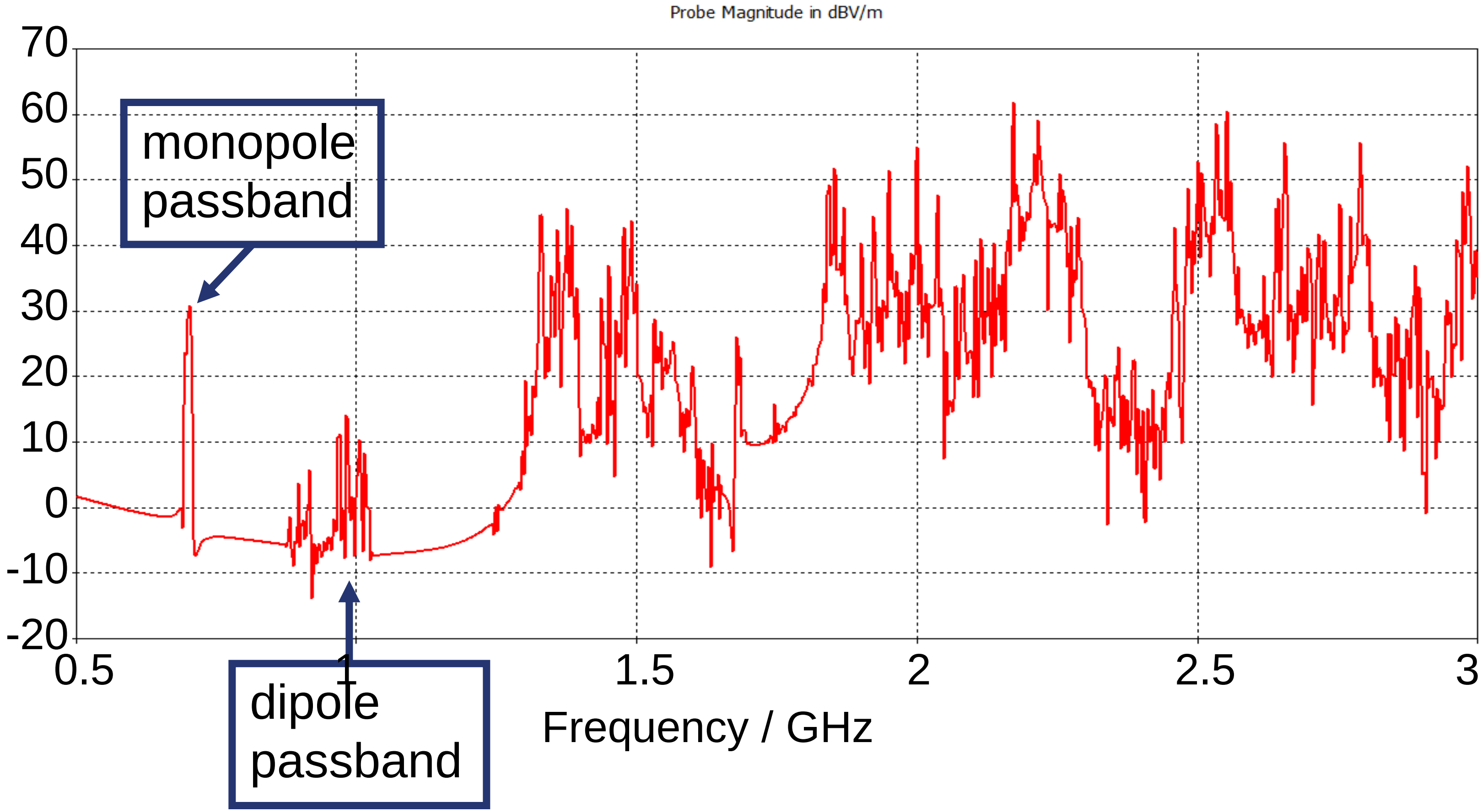
- Probe Time Signal



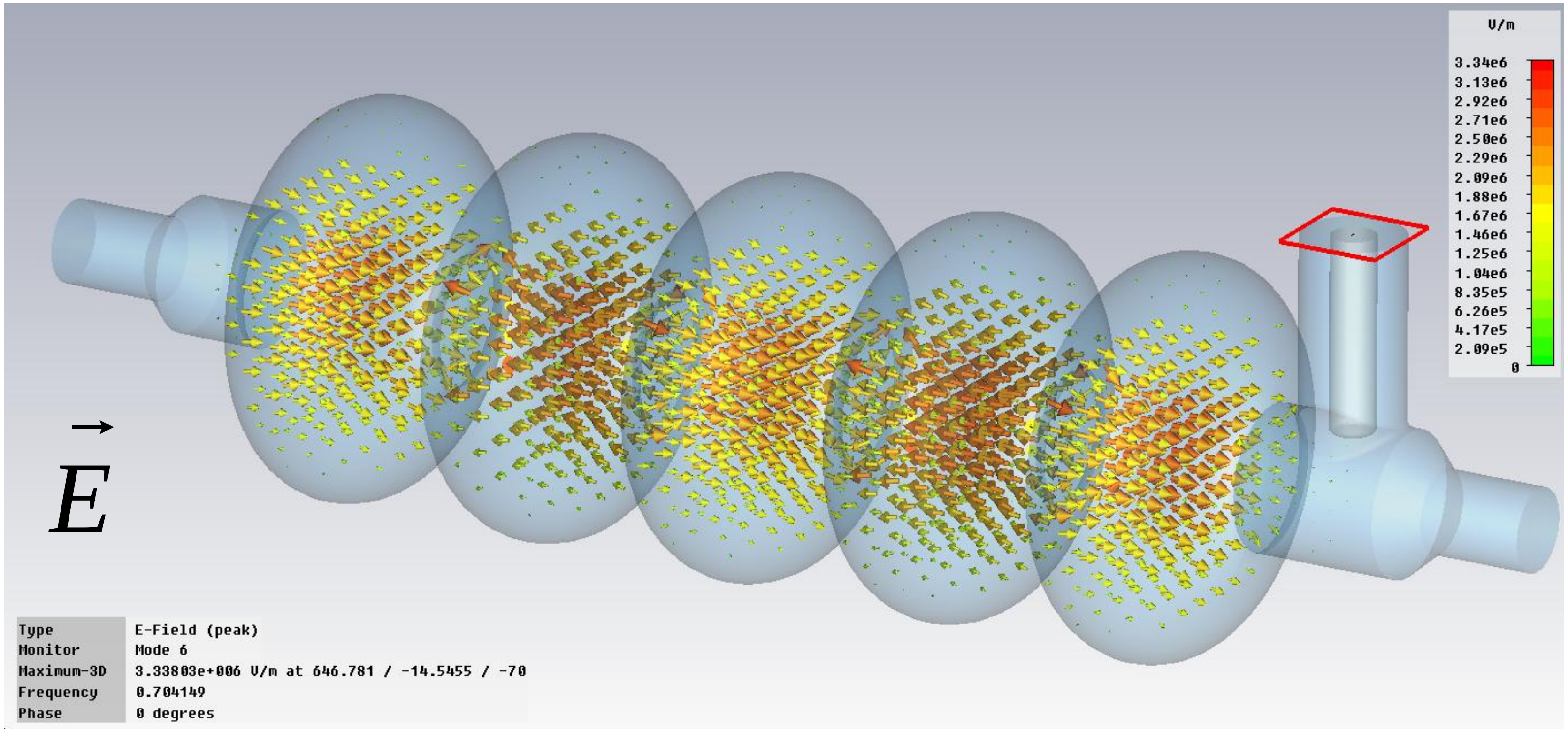
Field Simulation in Time Domain

- Using the Fourier transform => Transmission spectrum



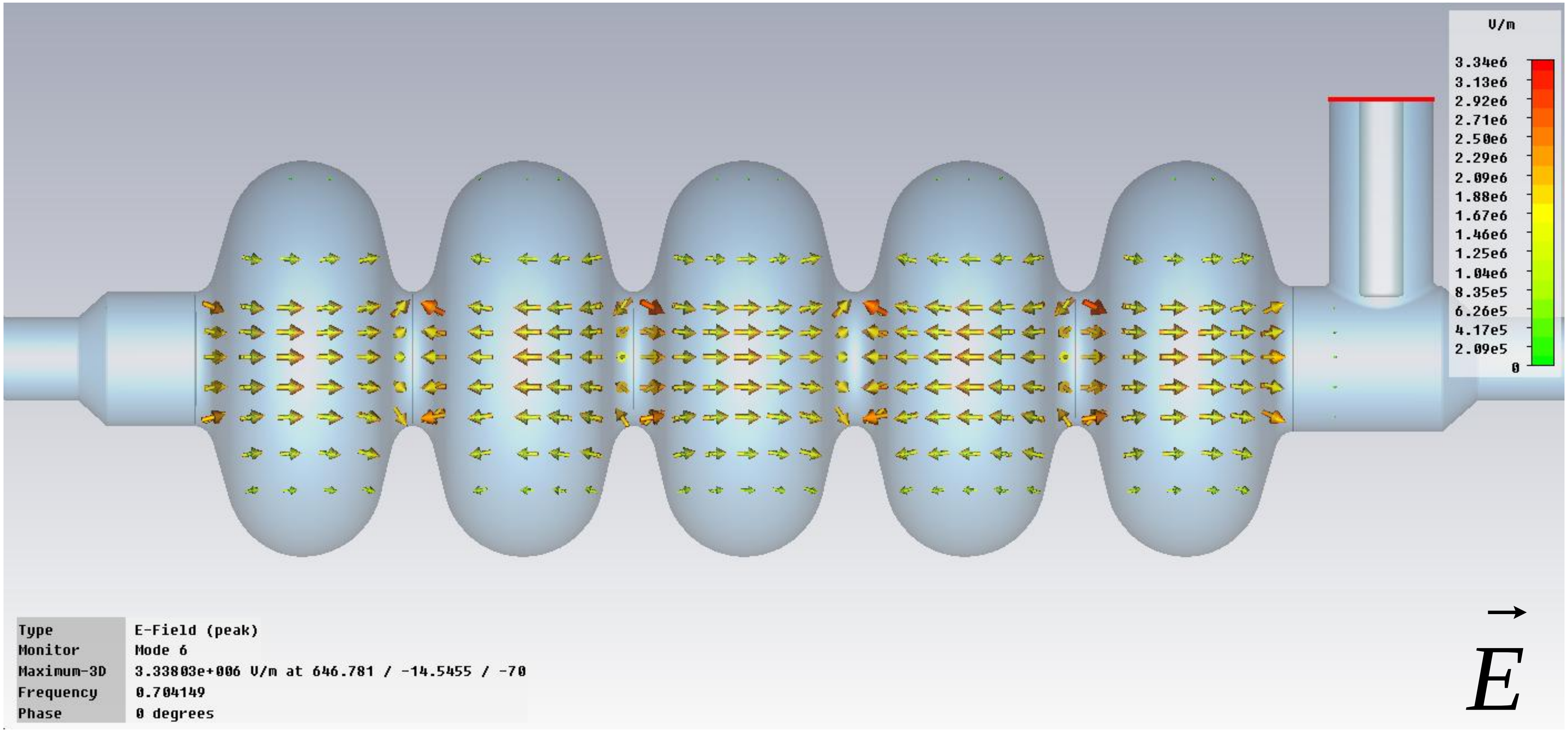
Field Simulation in Frequency Domain

- Calculation of the resonance frequencies and the corresponding eigenmodes



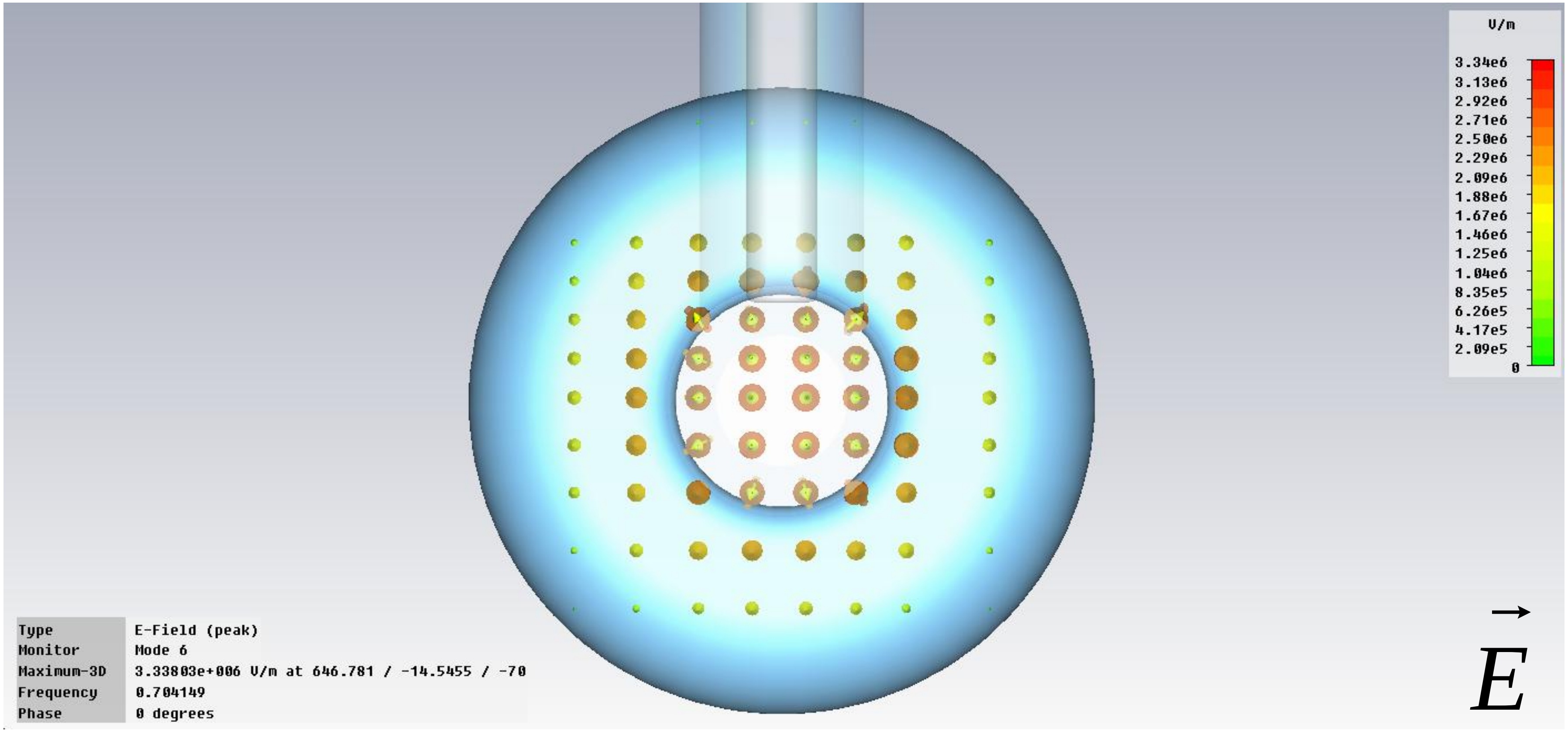
Field Simulation in Frequency Domain

- The TM010 Pi-mode for particle acceleration



Field Simulation in Frequency Domain

- The TM010 Pi-mode for particle acceleration



Detection of the Eigenmodes in Transmission Spectrum

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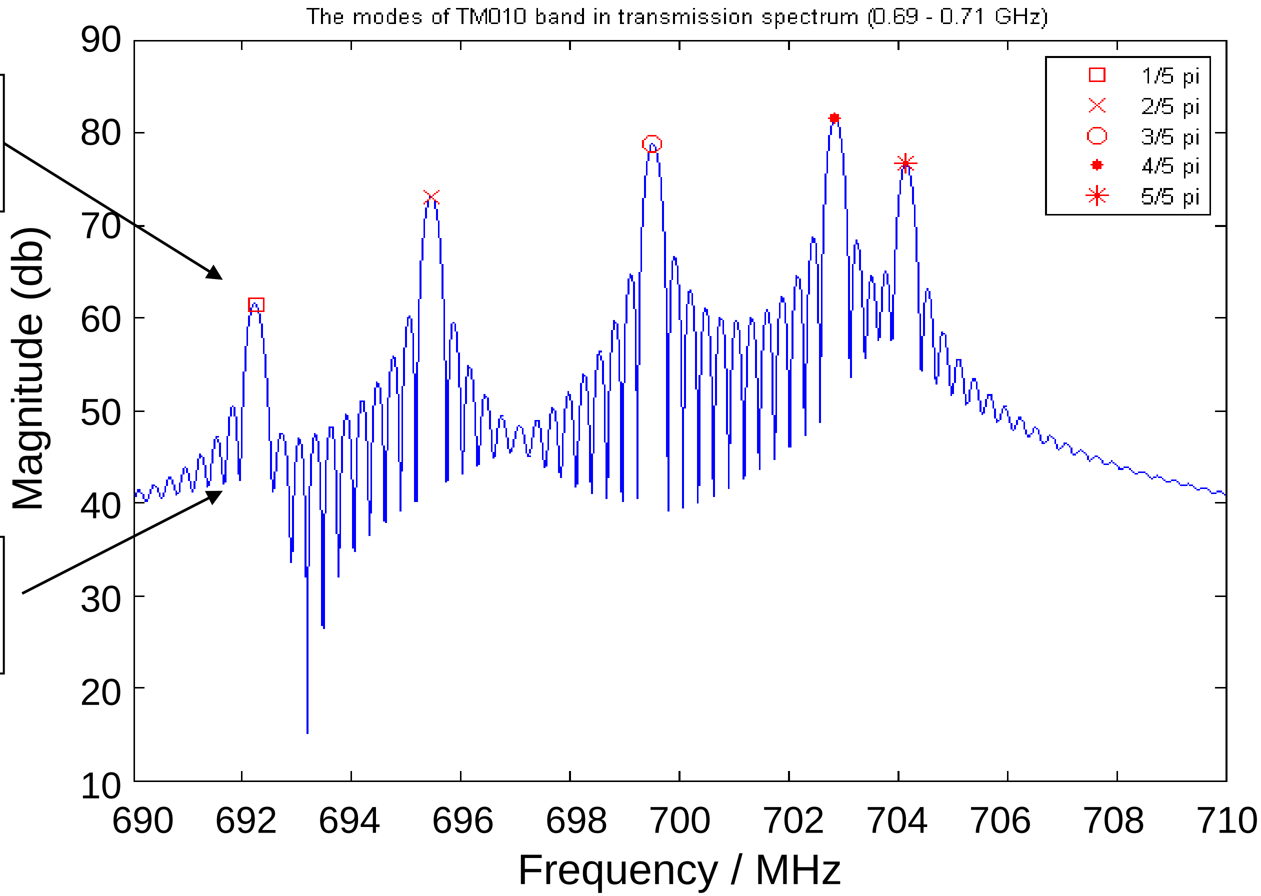
- The modes of the TM010 band

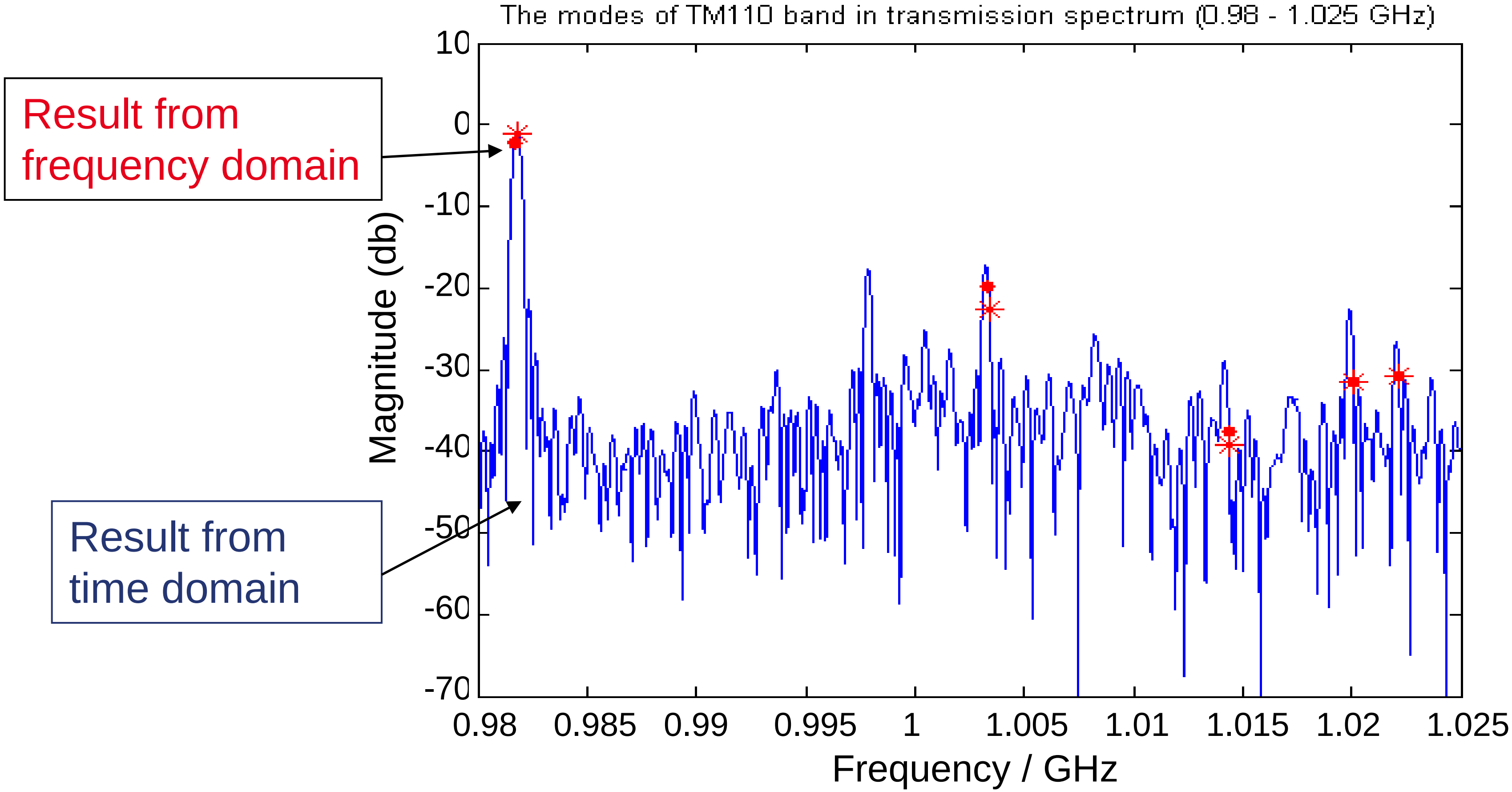
Result from frequency domain

Result from time domain



Detection of the Eigenmodes in Transmission Spectrum

- The modes of the TM110 band

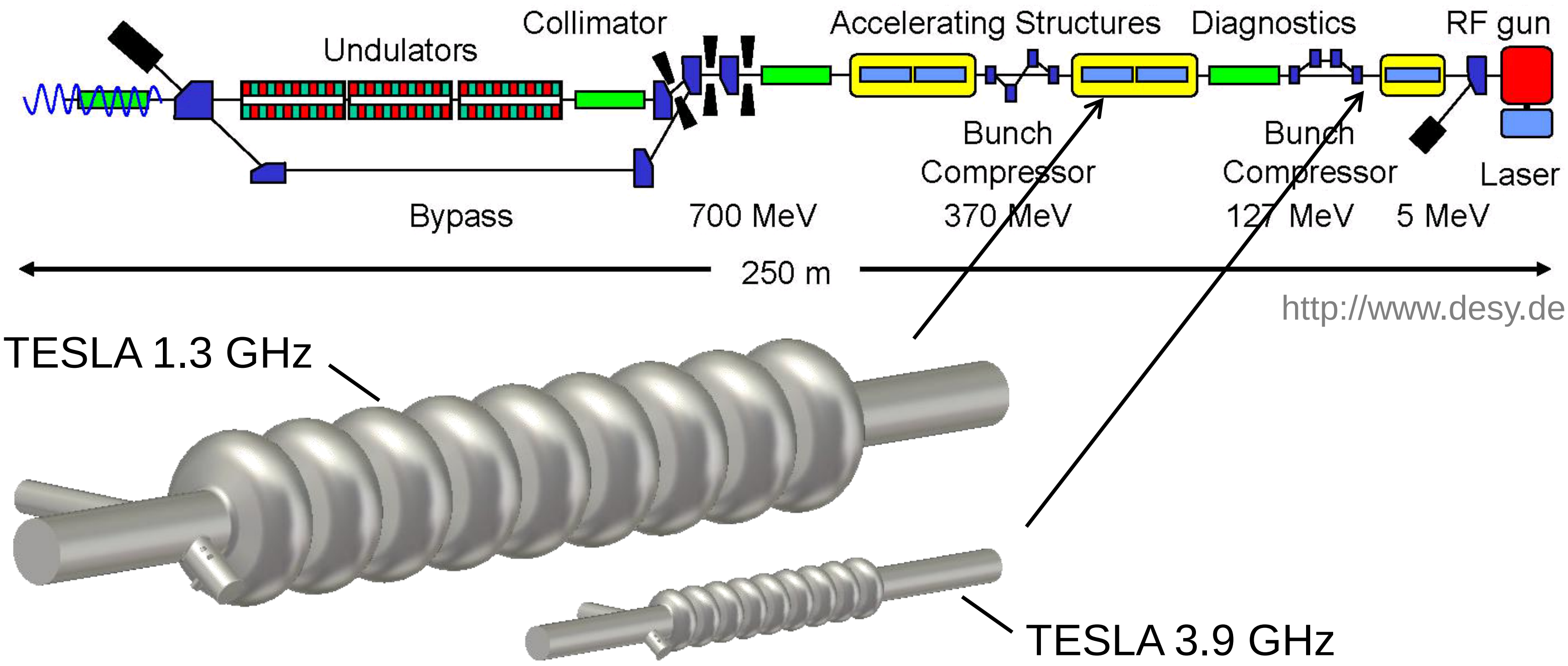


Future Work

- Simulation with higher resolution by means of higher order curvilinear elements
- Detection of all higher order modes (HOMs) in the transmission spectrum up to 3 GHz
- Damping consideration for HOM-couplers

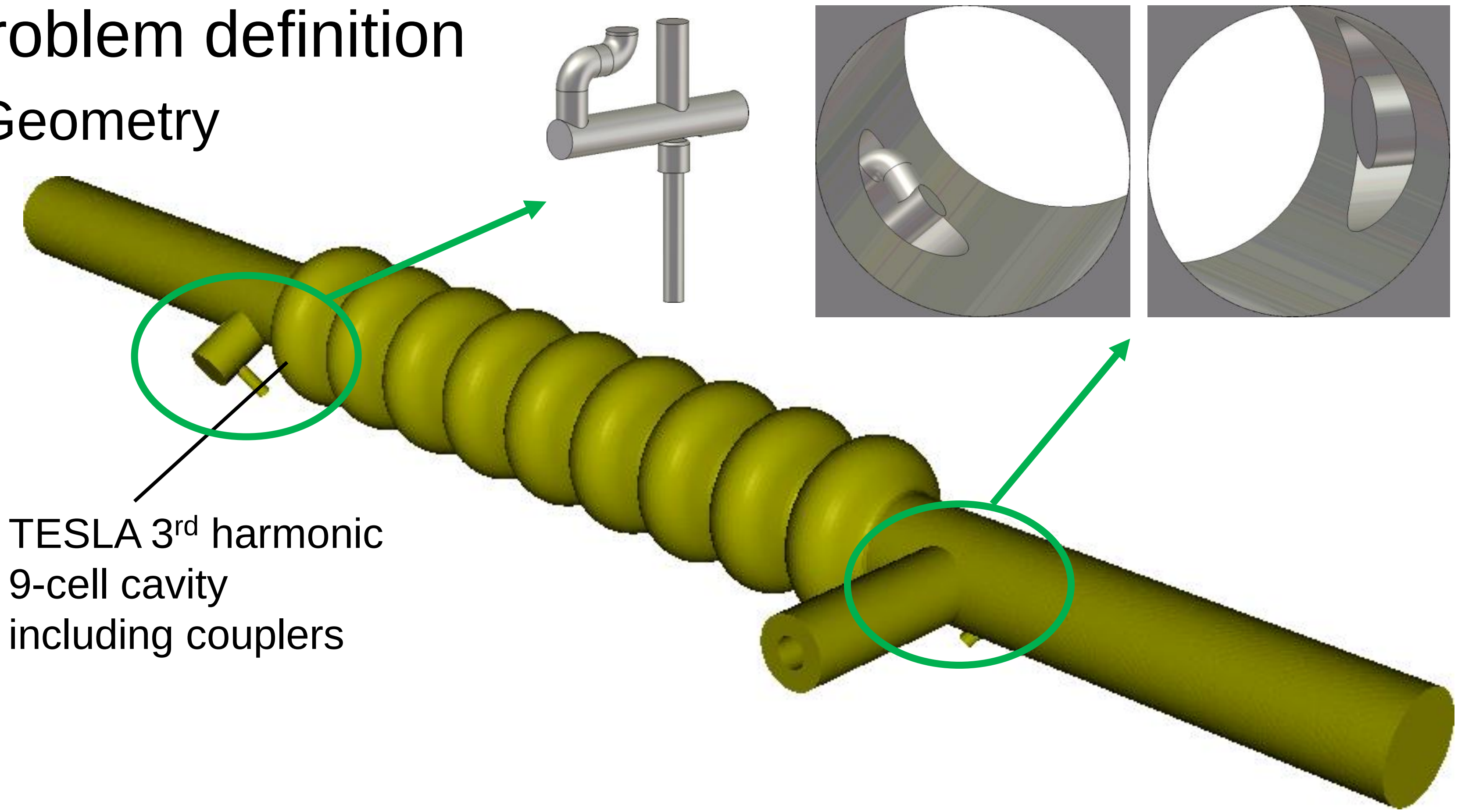
Cavity Simulations

- Particle accelerators
  - FLASH at DESY, Hamburg



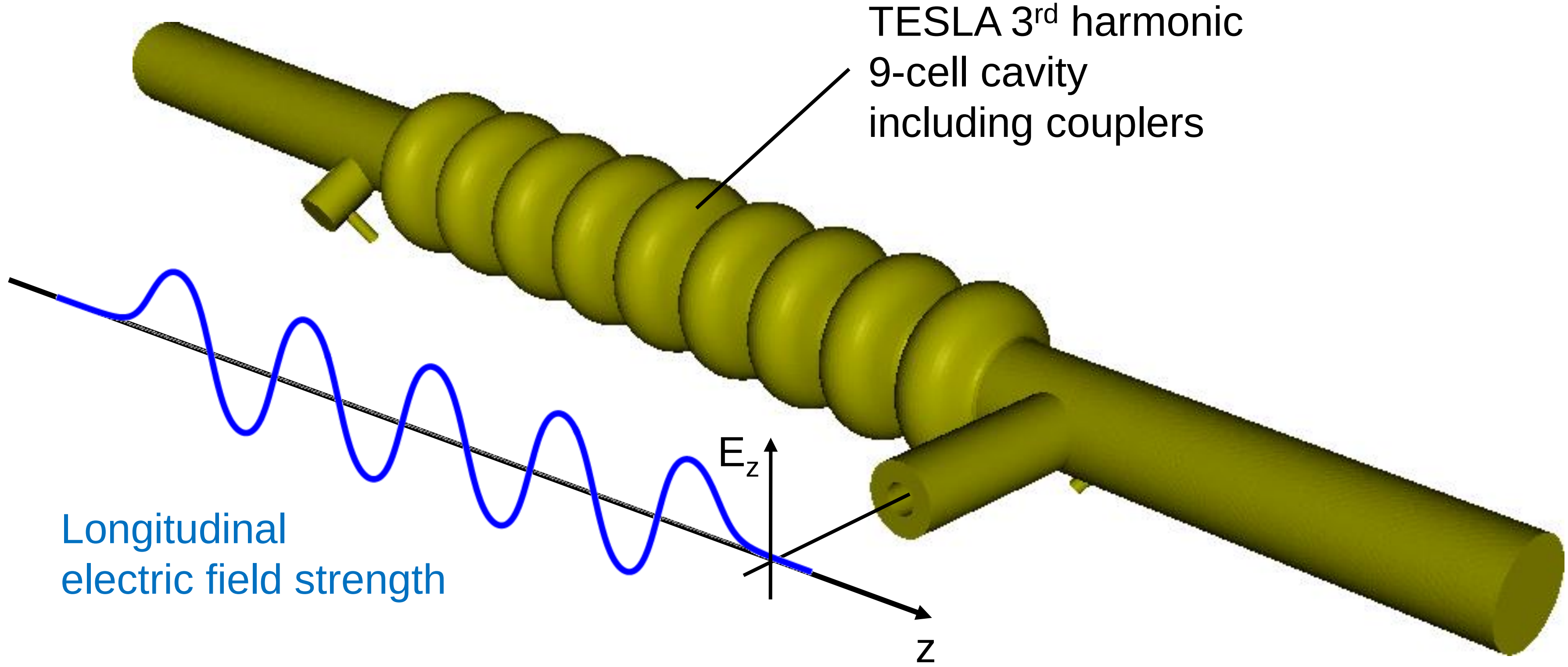
Elliptic Cavity with Couplers

- Problem definition
  - Geometry



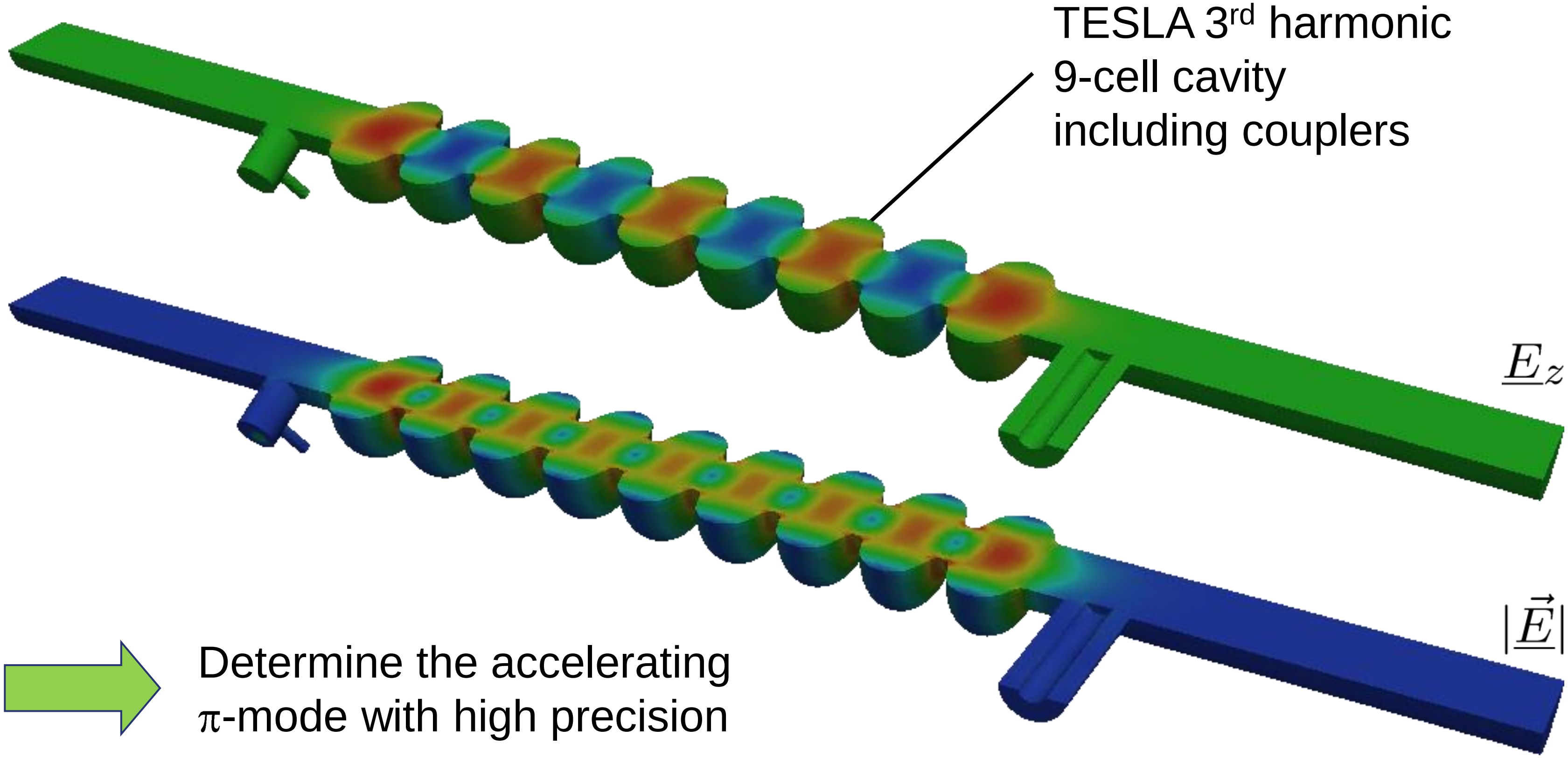
Fundamental Mode

- Problem definition
  - Accelerating field



High Precision Field Calculations

- Problem definition
  - Accelerating field

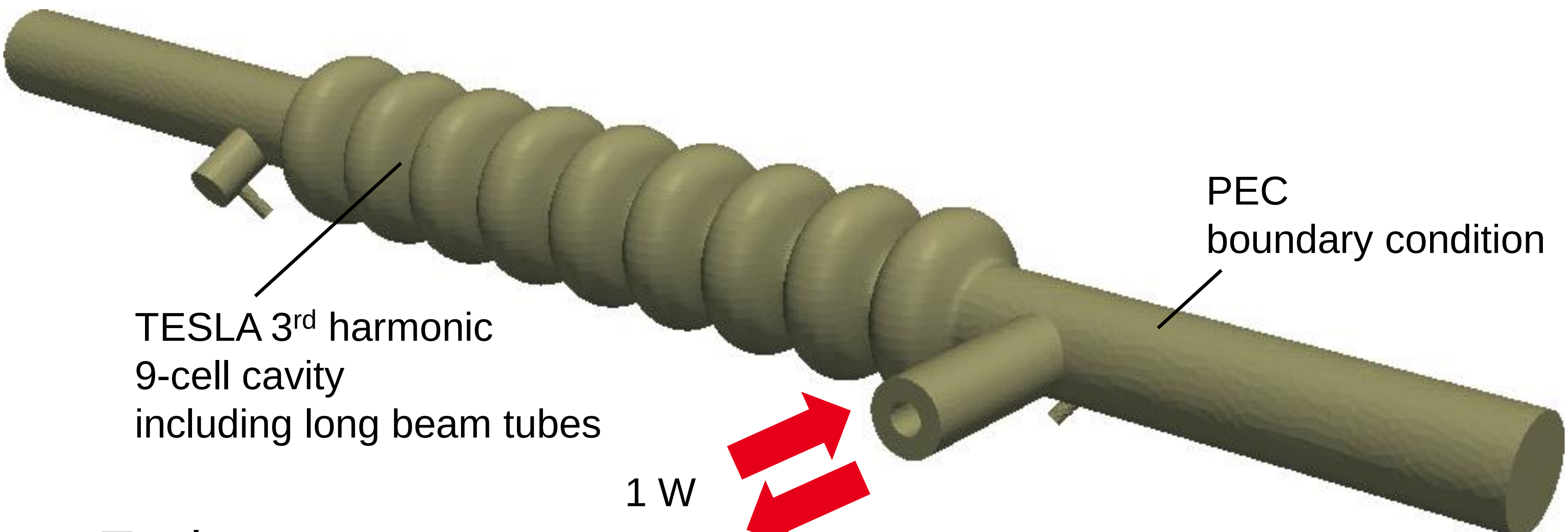


Determine the accelerating π-mode with high precision

Simulation Setup

- Problem definition

  - Geometry



  - Task

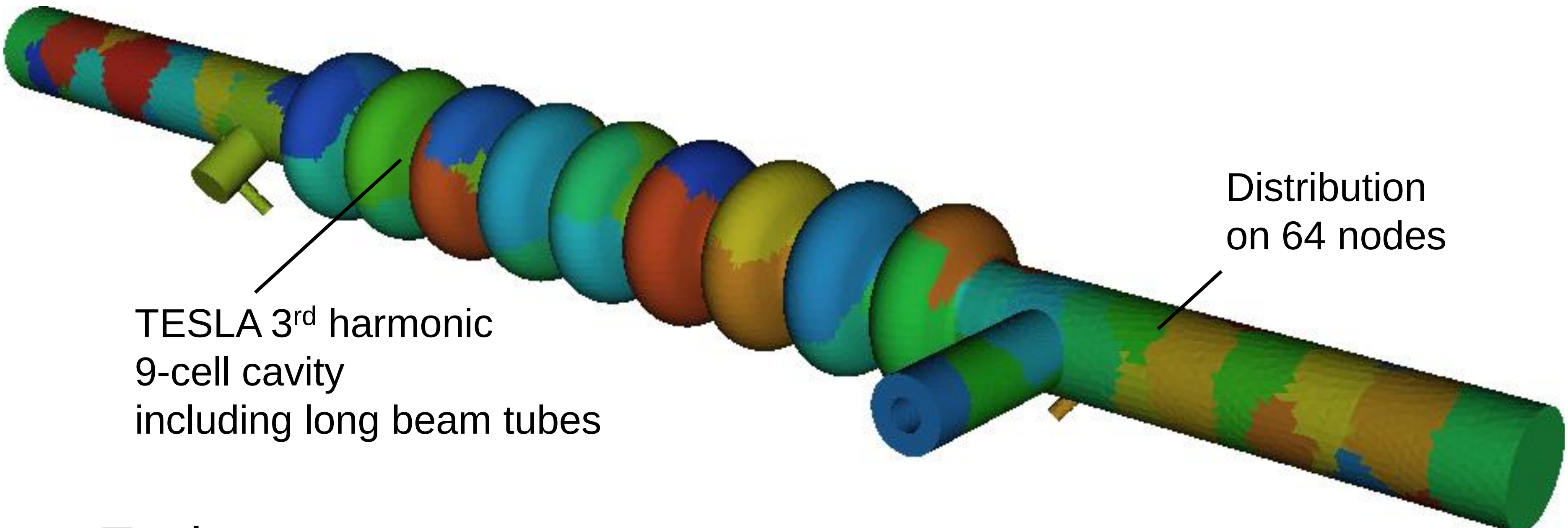
    Search for the π - mode field distribution

Grid: CST – STUDIO SUITE®

Parallelisation on Cluster Computer

ParMeTiS and VTK

- Problem definition
  - Geometry



TESLA 3rd harmonic
9-cell cavity
including long beam tubes

Distribution
on 64 nodes

  - Task

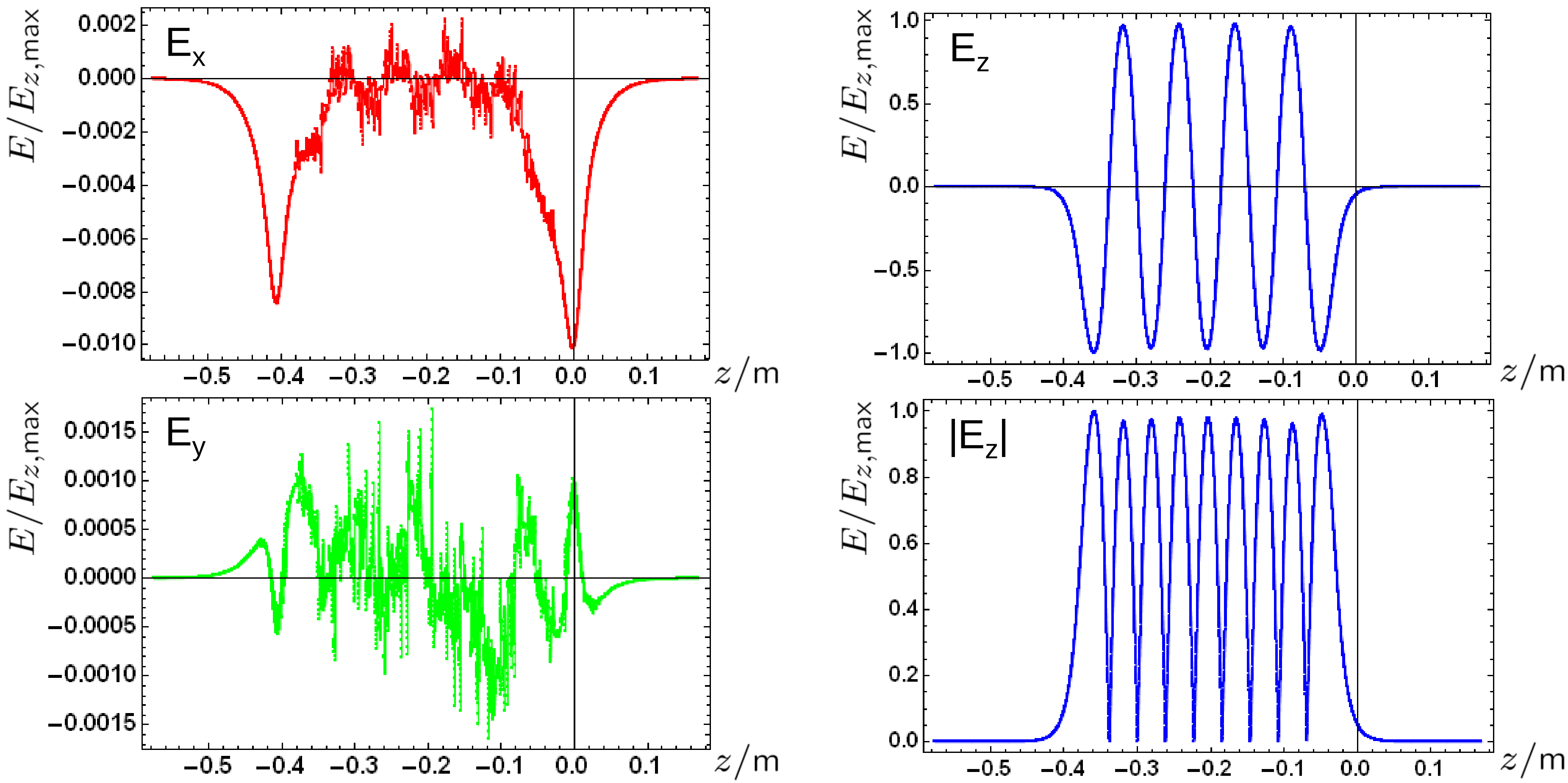
    Search for the π - mode field distribution

Grid: CST - Studio Suite®

Electric Field on Cavity Axis

585 409 cells, unsymmetric mesh

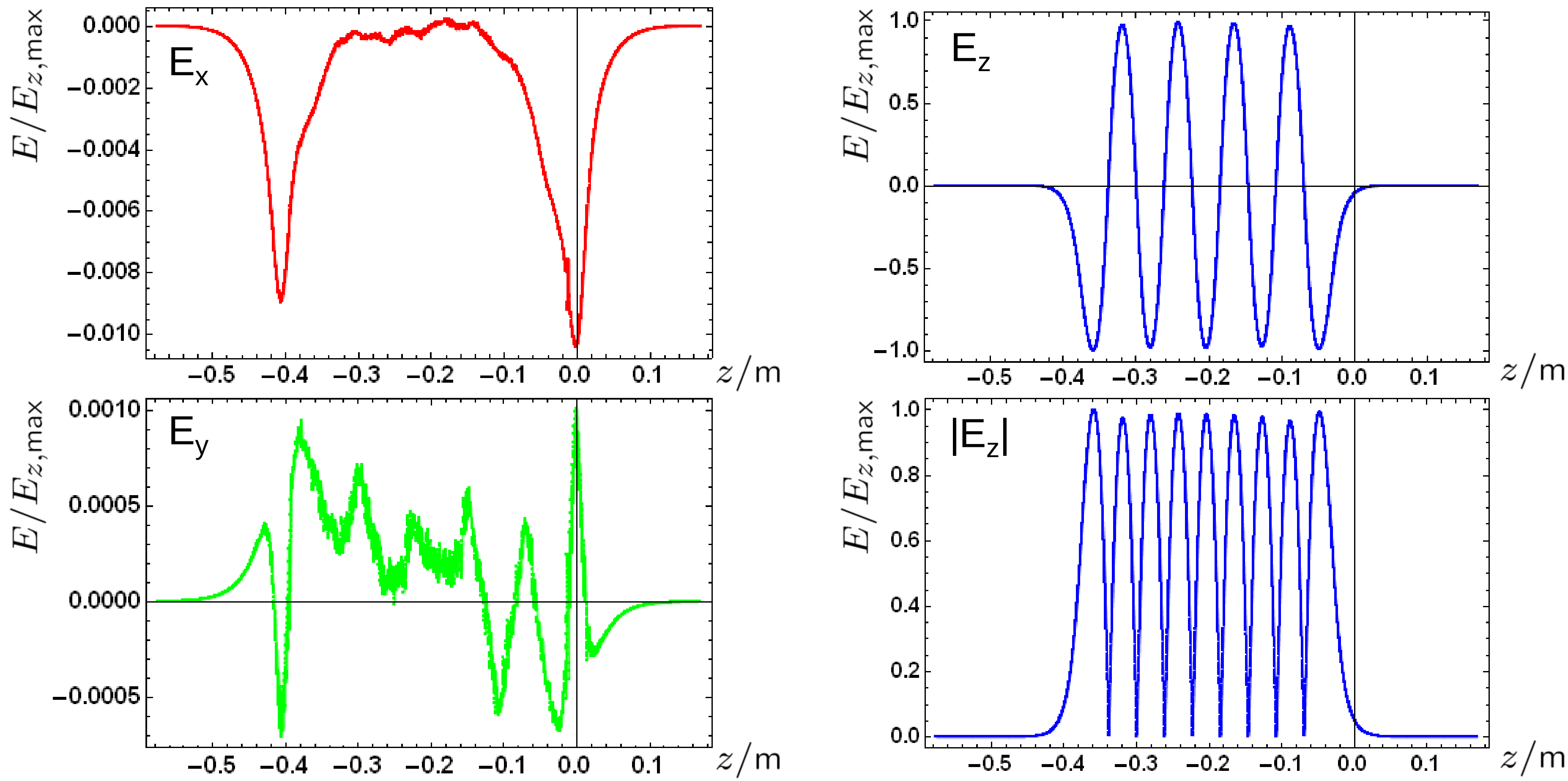
- Simulation results



Higher Resolution

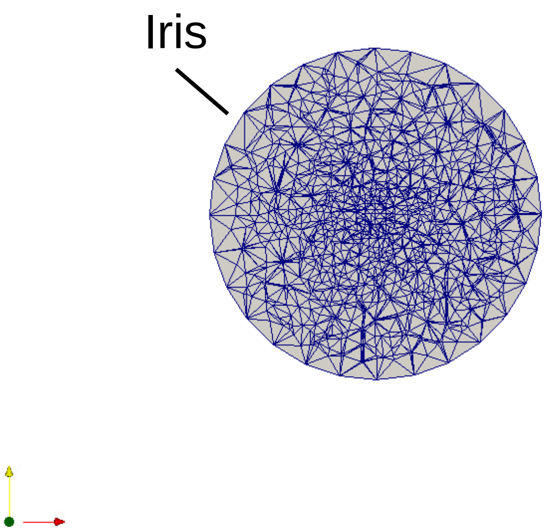
- Simulation results

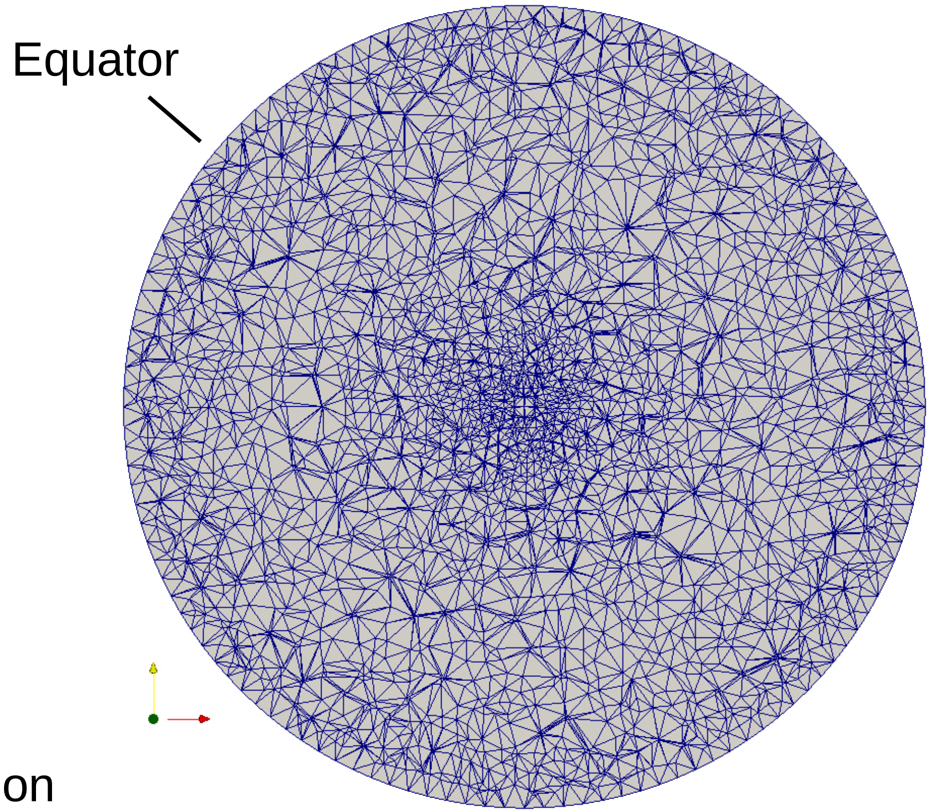
908 268 cells, unsymmetric mesh



Mesh has to be Symmetric

- Transversal grid information
  - Cut plane plots



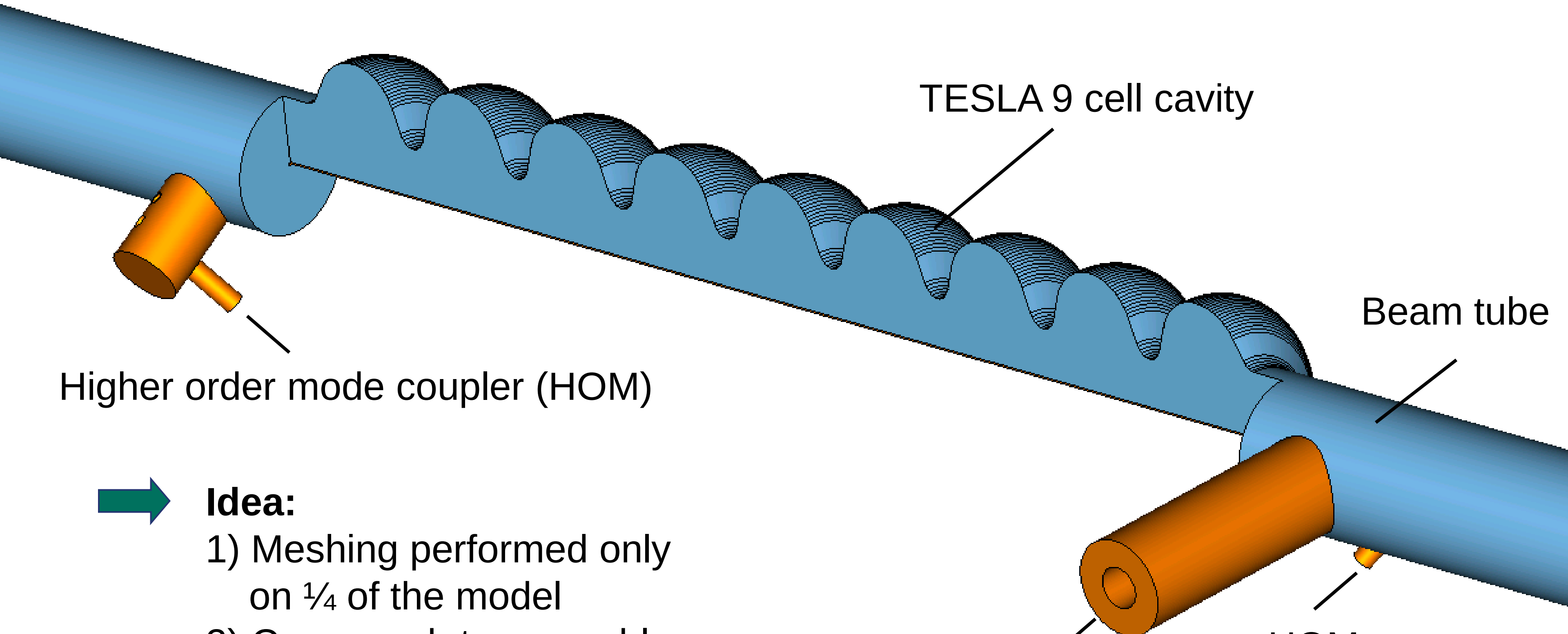


➡ unsymmetric mesh generation

Construction of Symmetric Mesh

CST - Studio Suite®

- Symmetric mesh generation

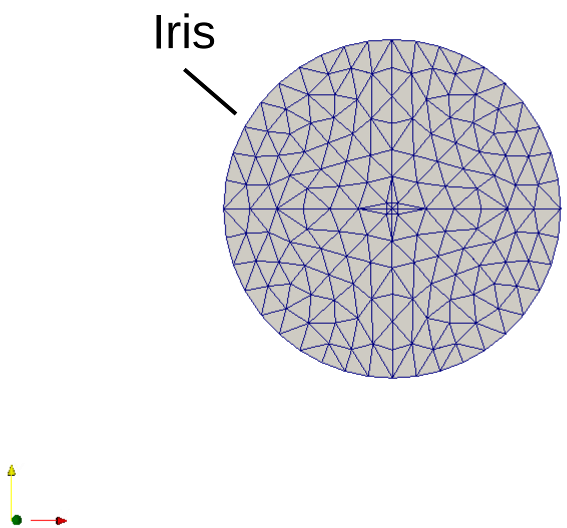


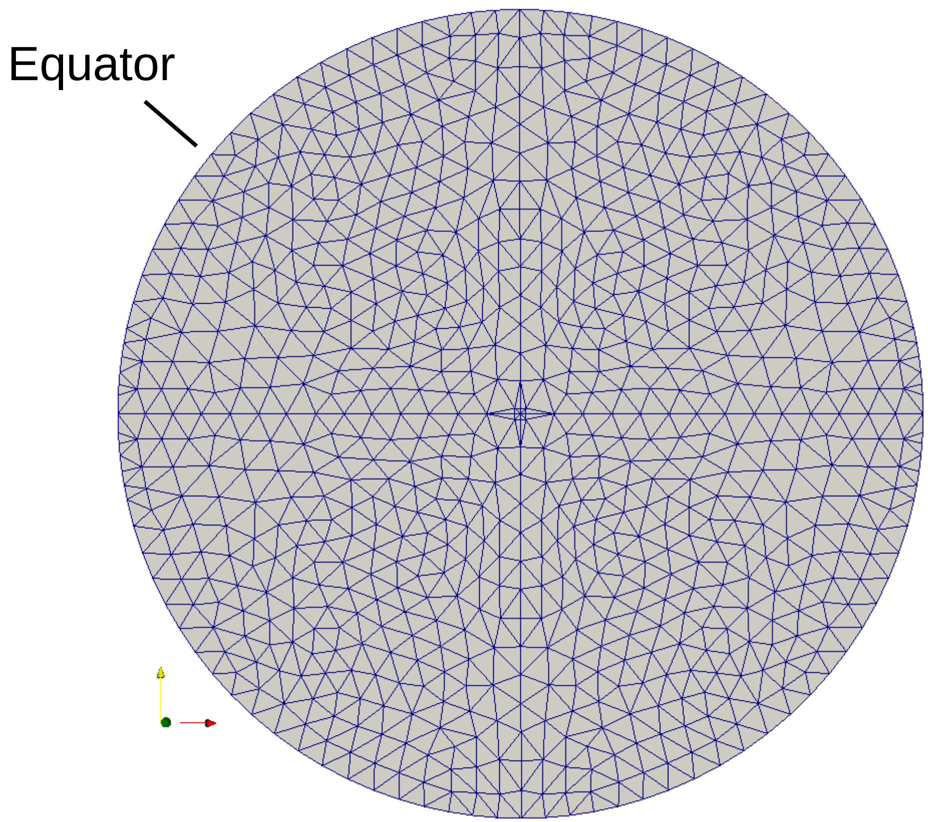
Idea:

1) Meshing performed only on ¼ of the model
2) Copy mesh to assemble the full information

Mirror Symmetric Mesh

- Transversal grid information
  - Cut plane plots





➡ symmetric mesh generation

Transversal Forces on Particles

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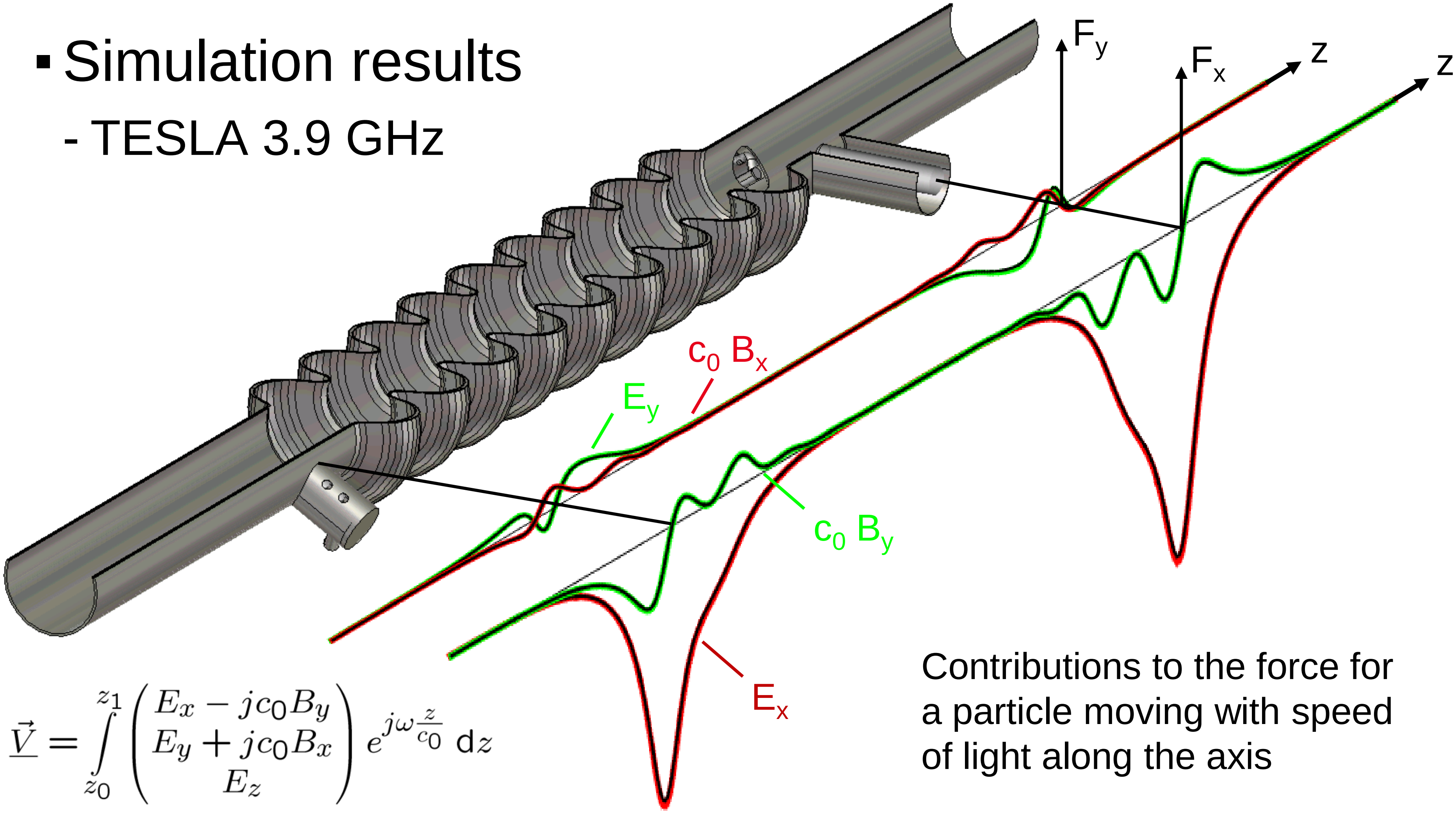
- Simulation results
  - TESLA 3.9 GHz

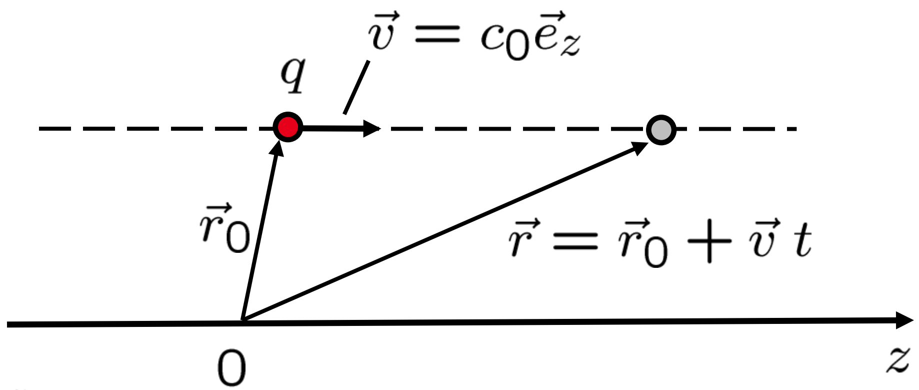


$$\underline{\vec{V}} = \int_{z_0}^{z_1} \begin{pmatrix} E_x - j c_0 B_y \\ E_y + j c_0 B_x \\ E_z \end{pmatrix} e^{j\omega \frac{z}{c_0}} \, \mathrm{d}z$$

Contributions to the force for a particle moving with speed of light along the axis

Integrated Forces

- Integrated forces



$$\underline{\vec{U}} = \int_{t_0}^{t_1} \frac{1}{q} \underline{\vec{F}} \mathrm{d}t$$

$$= \int_{z_0}^{z_1} \begin{pmatrix} E_x - jc_0 B_y \\ E_y + jc_0 B_x \\ E_z \end{pmatrix} e^{j\omega \frac{z - z_0}{c_0}} \frac{1}{c_0} \, \mathrm{d}z$$

$$= \frac{1}{c_0} e^{-j\omega \frac{z_0}{c_0}} \underbrace{\int_{z_0}^{z_1} \begin{pmatrix} E_x - jc_0 B_y \\ E_y + jc_0 B_x \\ E_z \end{pmatrix} e^{j\omega \frac{z}{c_0}} \, \mathrm{d}z}_{\underline{\vec{V}}}$$

➡ Quantity used to characterize the fields (kick factors) $\left(\frac{V_x}{V_z}, \frac{V_y}{V_z}\right)$

Resulting Kick Factors

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- Integrated forces

1 904 470 Cells
11 780 962 DOFs

3 282 467 Cells
20 370 322 DOFs

TESLA 3.9 GHz (lower resolution)

Full:

$$\frac{10^6}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-525.8+172.4\,j\\8.5+377.2\,j\end{pmatrix}$$

Upstream:

$$\frac{10^6}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-137.9+269.7\,j\\-58.2+171.7\,j\end{pmatrix}$$

Downstream:

$$\frac{10^6}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-387.8-97.3\,j\\66.8+205.5\,j\end{pmatrix}$$

TESLA 3.9 GHz

Full:

$$\frac{10^6}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-534.2+174.0\,j\\8.1+383.6\,j\end{pmatrix}$$

Upstream:

$$\frac{10^6}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-141.8+276.1\,j\\-59.5+175.1\,j\end{pmatrix}$$

Downstream:

$$\frac{10^6}{V_z}\begin{pmatrix}V_x\\V_y\end{pmatrix}=\begin{pmatrix}-392.3-102.1\,j\\67.7+208.5\,j\end{pmatrix}$$

Summary / Outlook

- Summary:
  - Request for precise modeling of electromagnetic fields in resonant structures including small geometric details such as high power / HOM coupler
  - Geometric modeling with CST STUDIO SUITE®
  - Kick factor calculation for TESLA 1.3 GHz and 3.9 GHz
- Outlook:
  - Detailed study of longitudinal and transversal fields for accurate beam dynamics simulations for SPL / ESS?