Calculation of Eigenfields for the European XFEL Cavities

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TECHNISCHE UNIVERSITÄT DARMSTADT

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Overview

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- Task
  - Calculation of fields for the European XFEL cavities in 3D considering coupling ports as well as non-ideal geometries
    - Coupling ports

      Modeling of ports

      Integration of ports in the eigenvalue formulation
    - Non-ideal geometries

      Support flexible geometry description in 3D
  - Extraction of field components for beam dynamics simulations
    - Efficient data transfer and utilization of the electromagnetic fields

Numerical Modeling

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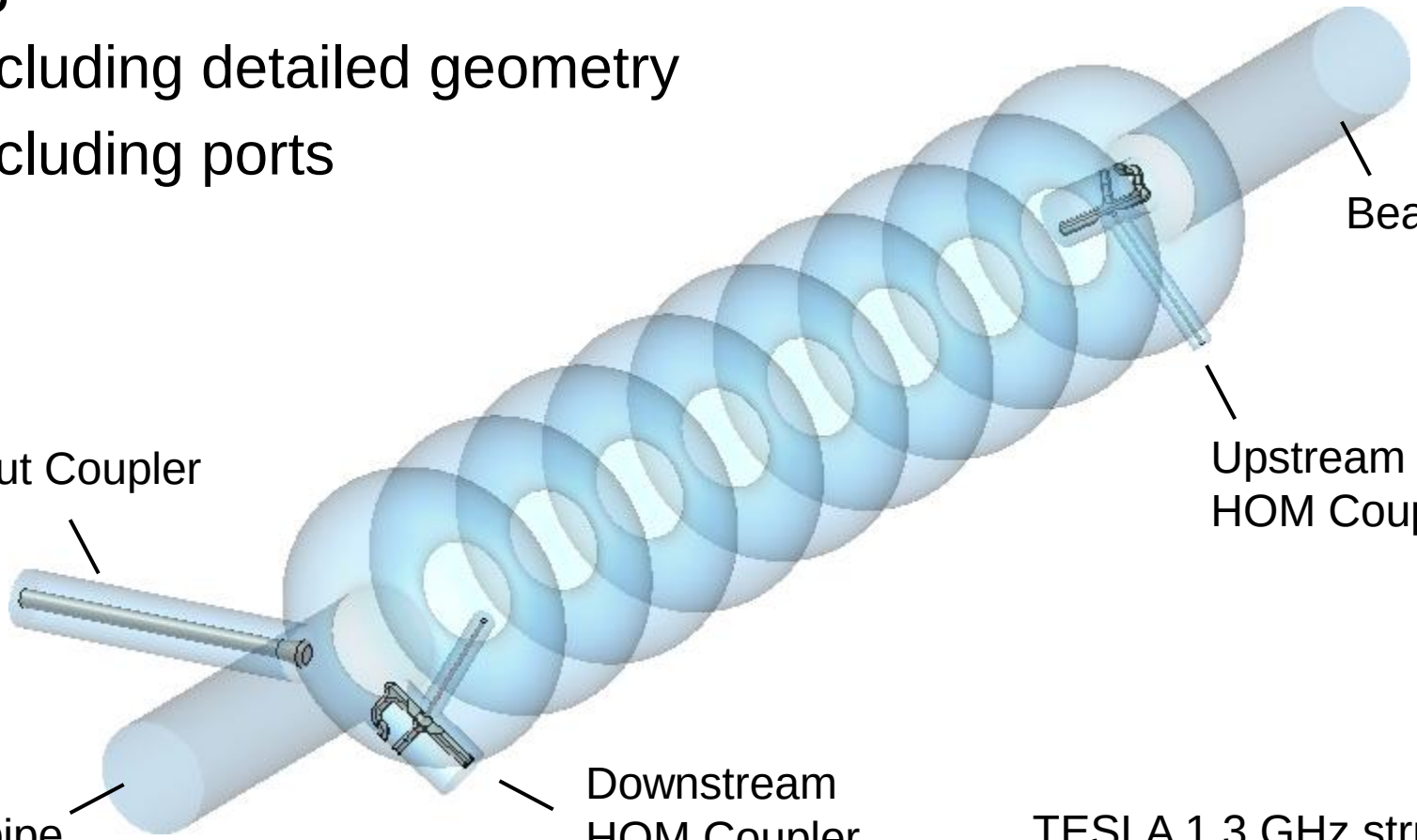
- Eigenvalue calculation
  - Including detailed geometry
  - Including ports



TESLA 1.3 GHz structure

Numerical Modeling

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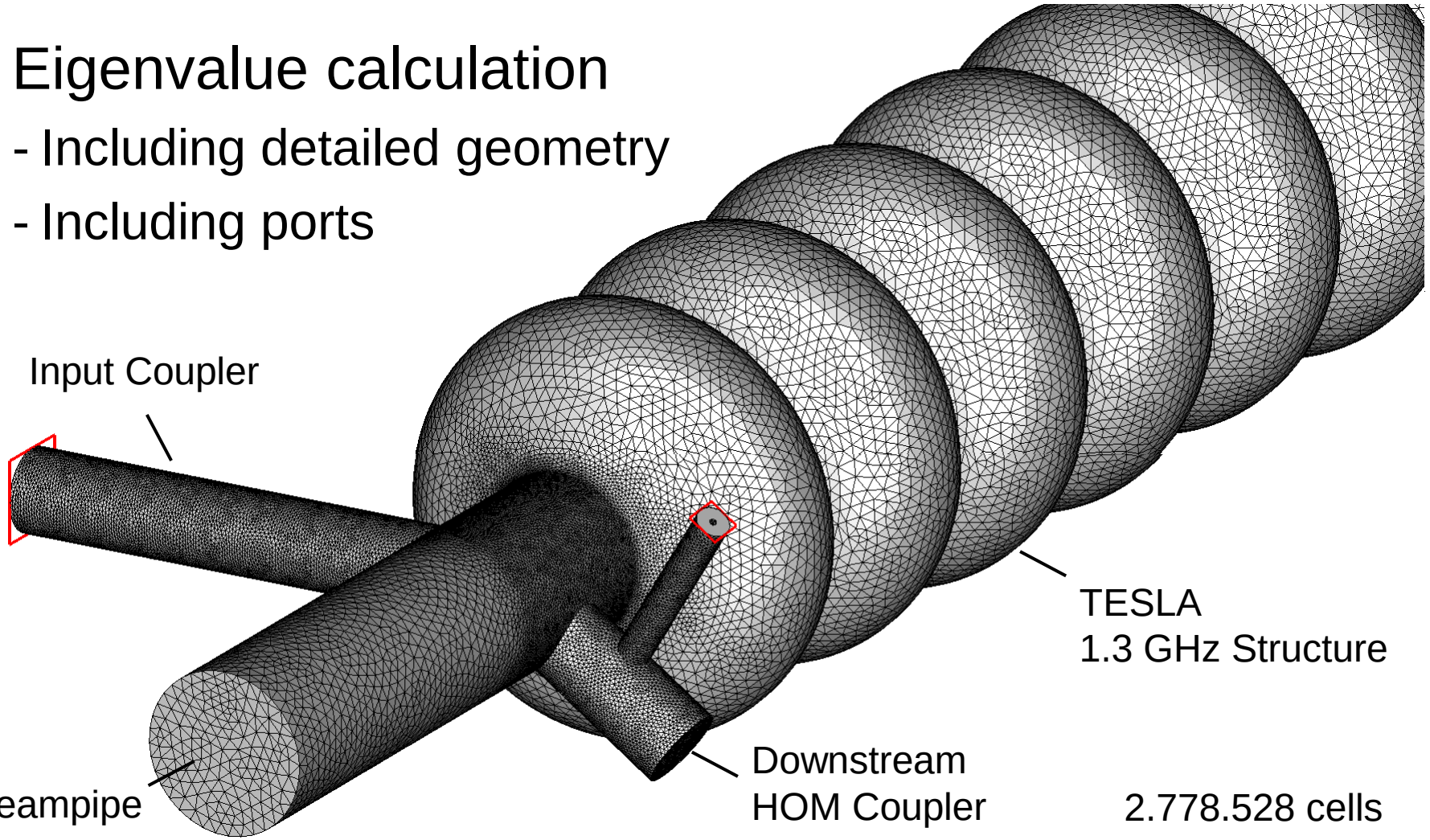

Numerical Modeling

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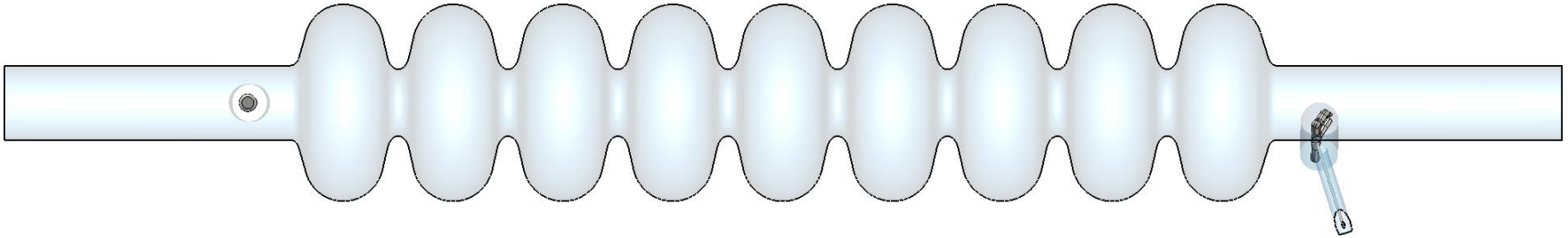
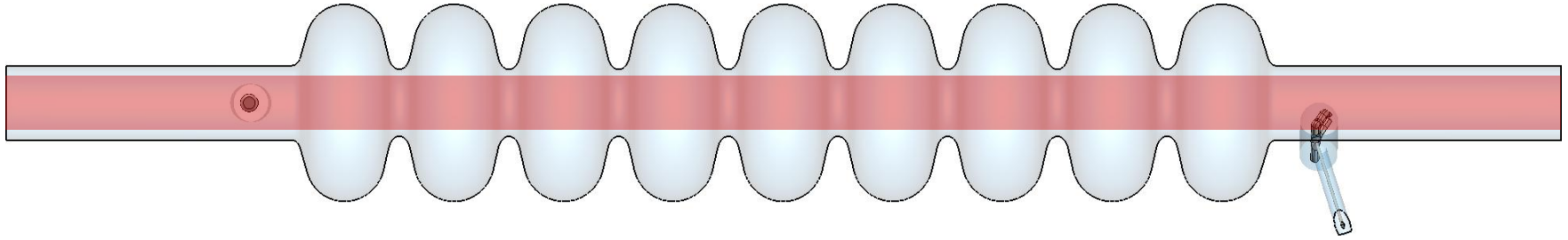
- Eigenmode calculation
  - Fields are calculated based on an unstructured grid
  - Ports are modeled with impedance boundary condition



- Beam dynamics simulation
  - Field components are needed in the vicinity of the axis only



Numerical Modeling

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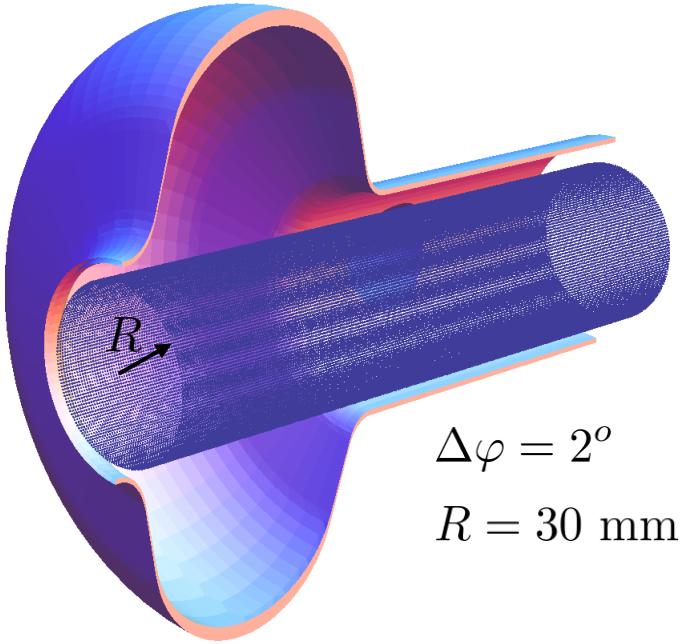
- Field reconstruction using the Kirchhoff integral
  - Field values inside a closed surface can be determined once the surface field components are available
  - Kirchhoff integral



$$\Delta\varphi = 2^o$$

$$R = 30\ \text{mm}$$

$$G = \frac{e^{-ik|\vec{r}-\vec{r}\,'|}}{4\pi|\vec{r}-\vec{r}\,'|} \qquad k = \frac{2\pi f}{c_0}$$

$$\vec{E}(\vec{r}) = \int \left(k(\vec{n}' \times ic_0\vec{B}')\, G - (\vec{n}' \times \vec{E}') \times \nabla G - (\vec{n}' \cdot \vec{E}')\, \nabla G \right) \mathrm{d}A'$$

$$ic_0\vec{B}(\vec{r}) = \int \left(k(\vec{n}' \times \vec{E}')\, G - (\vec{n}' \times ic_0\vec{B}') \times \nabla G - (\vec{n}' \cdot ic_0\vec{B}')\, \nabla G \right) \mathrm{d}A'$$

Numerical Modeling

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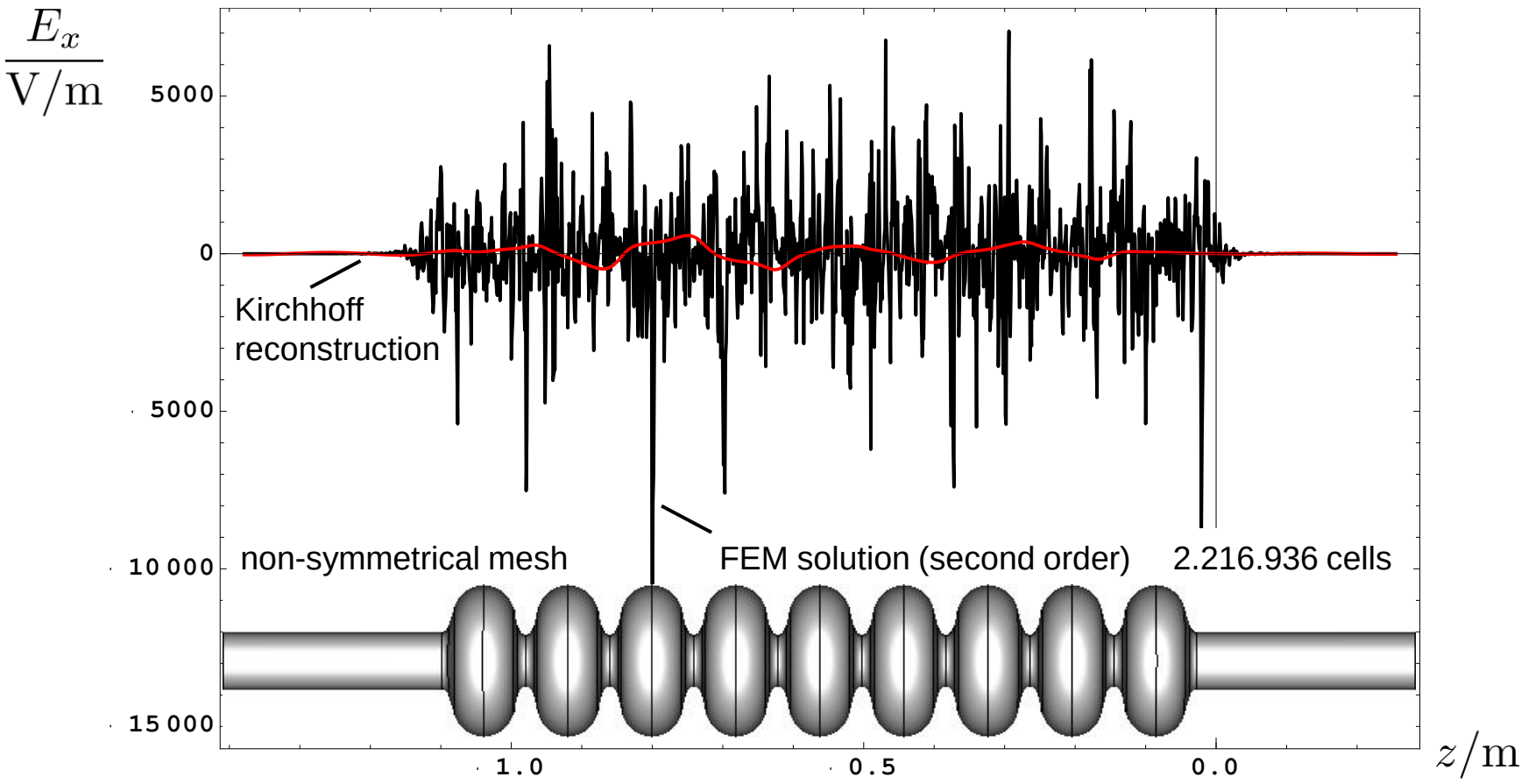

Numerical Modeling

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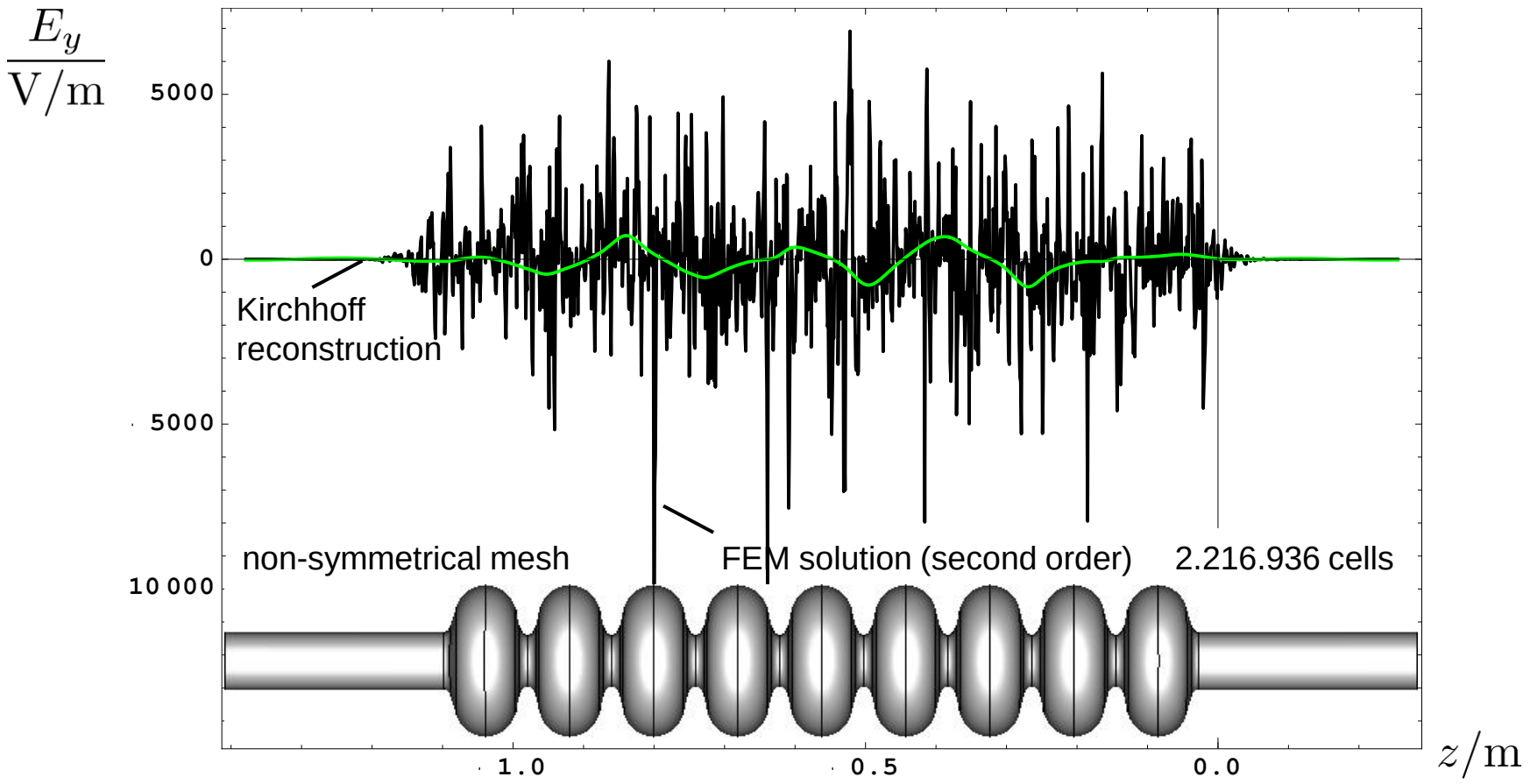

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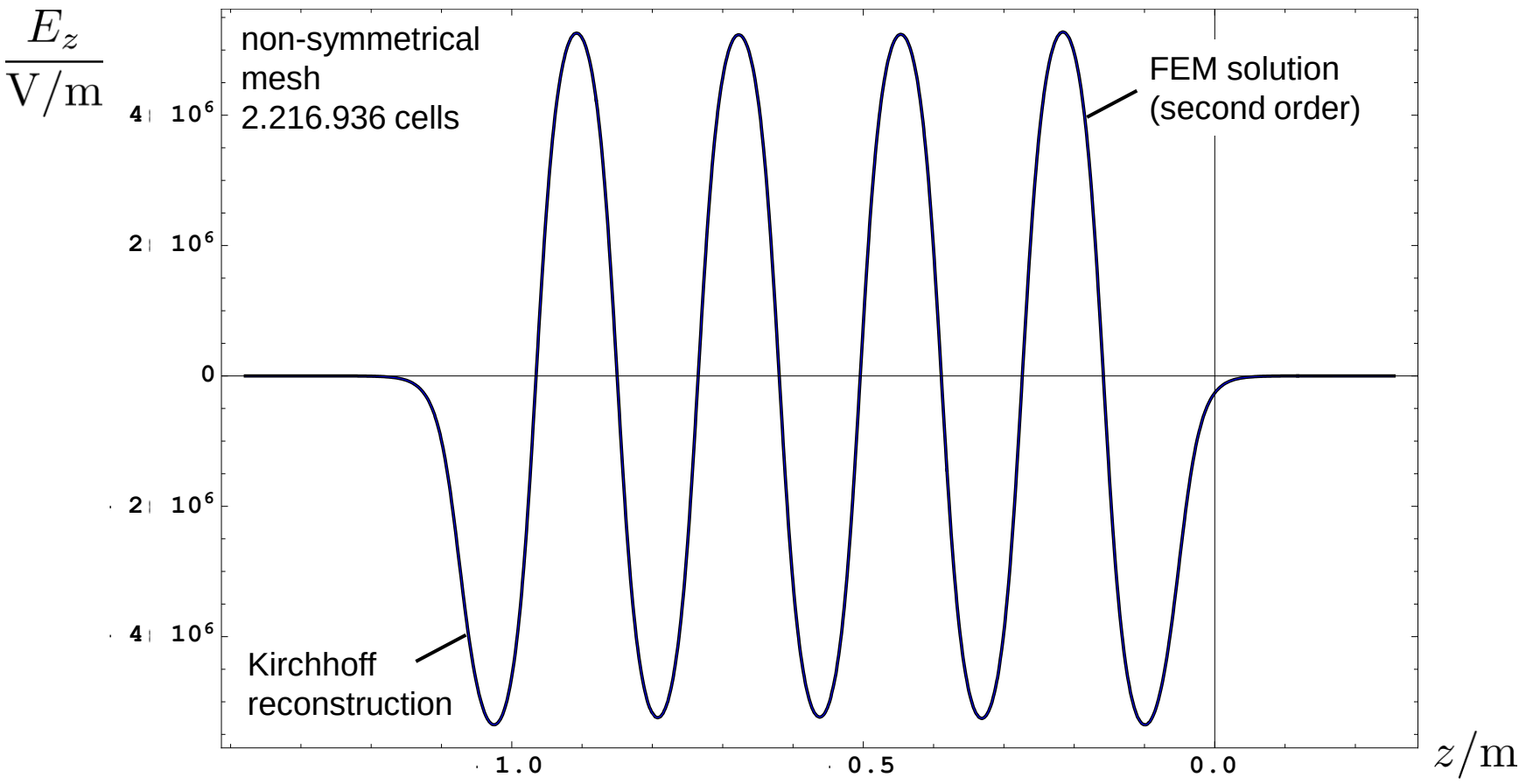

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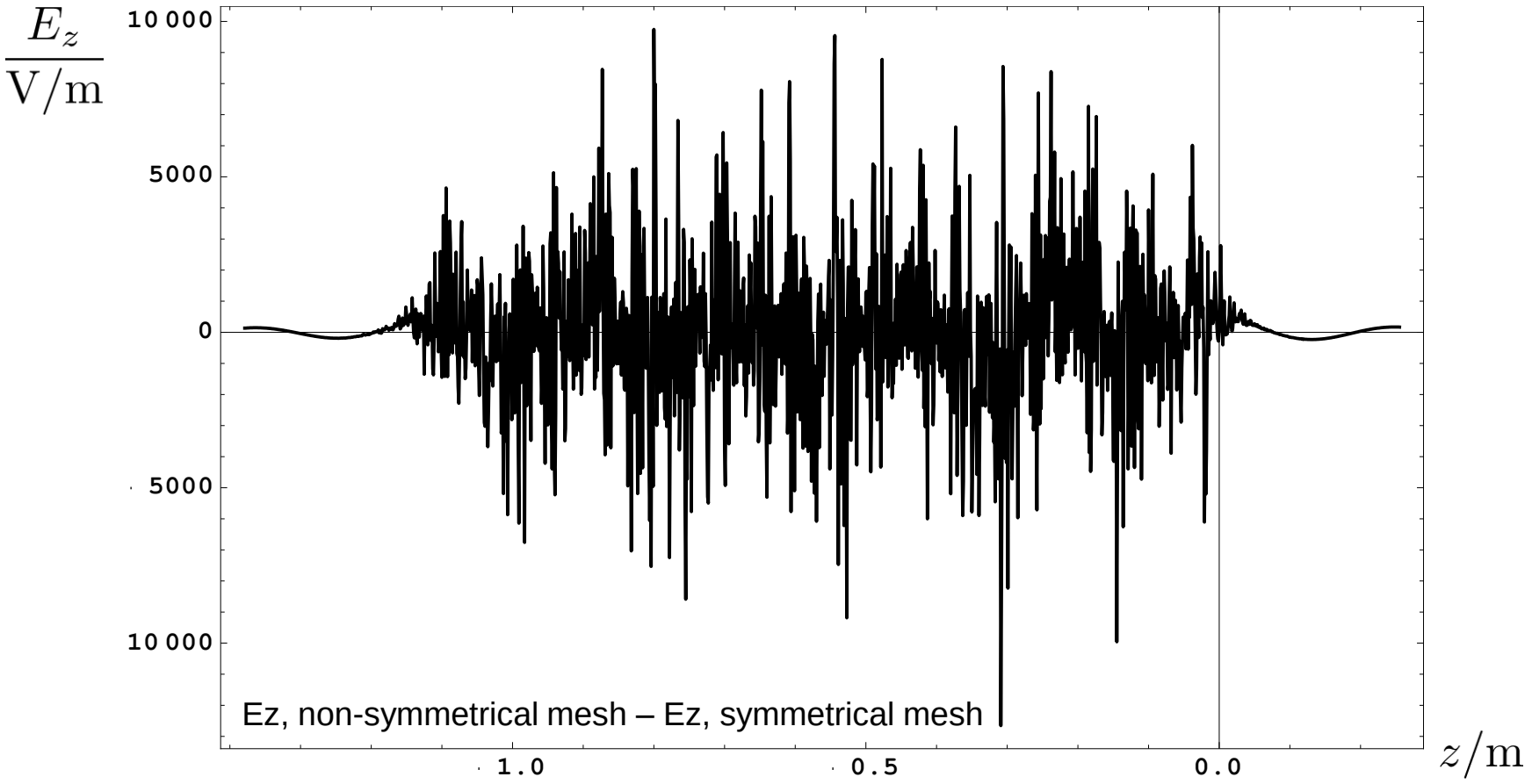

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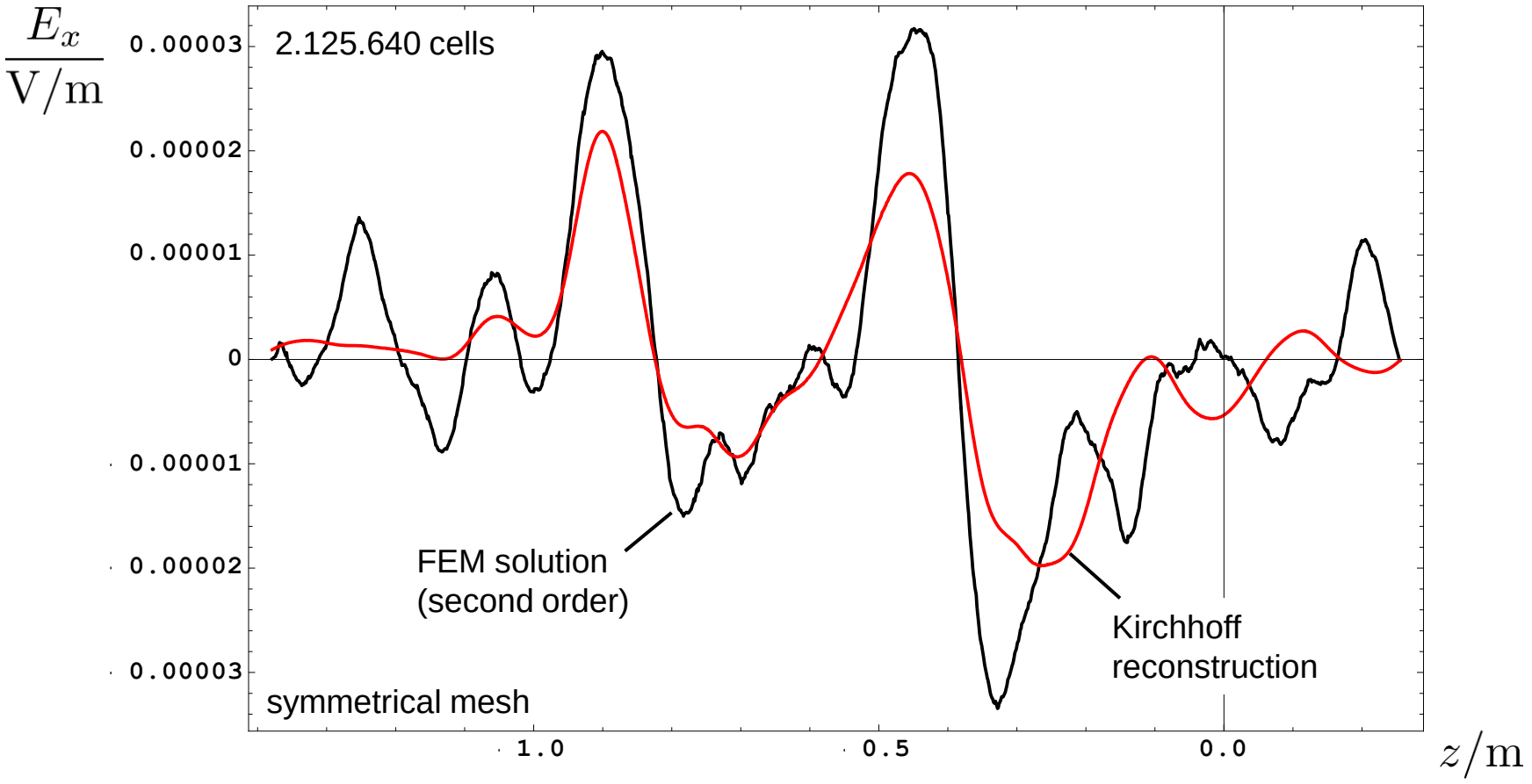

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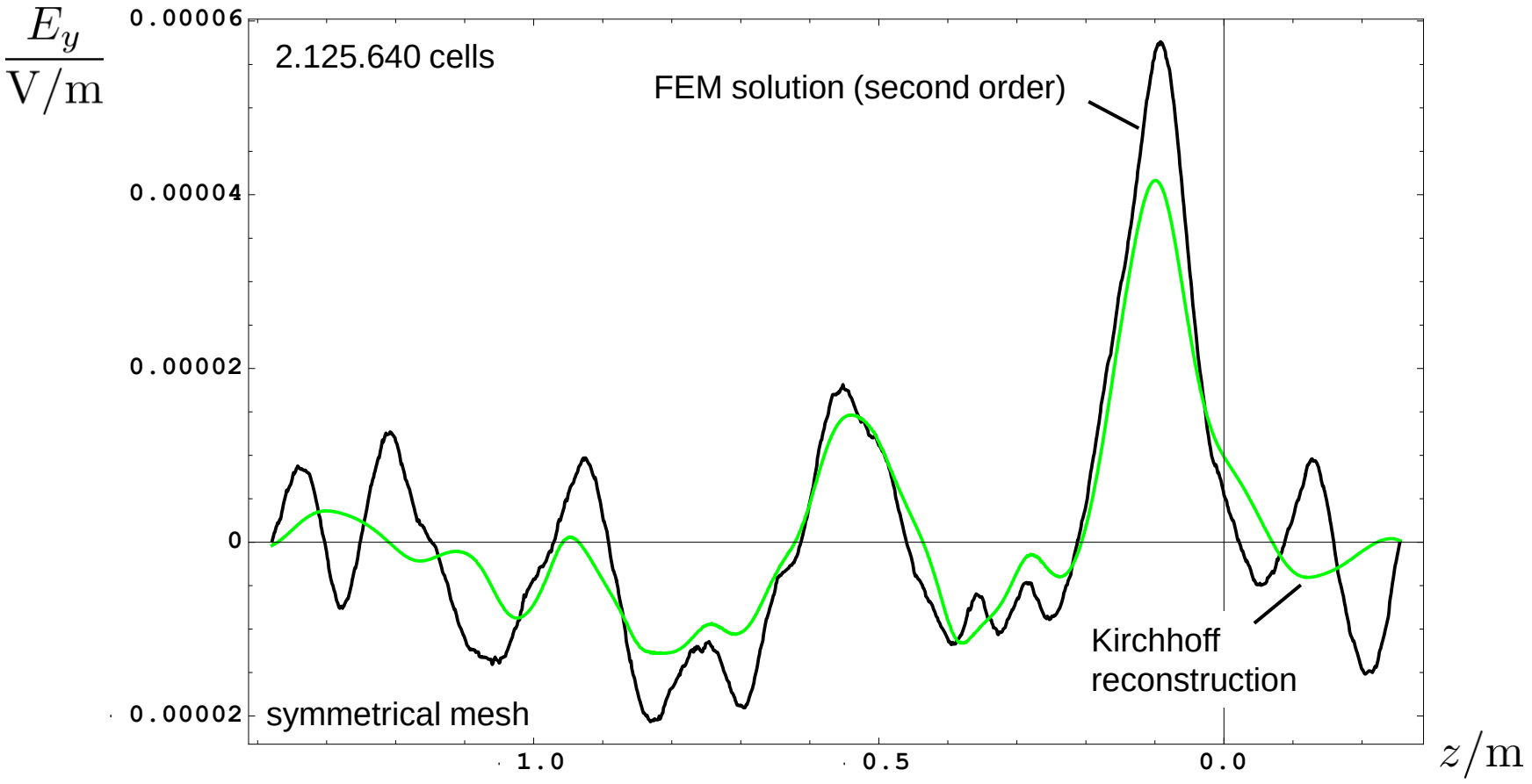

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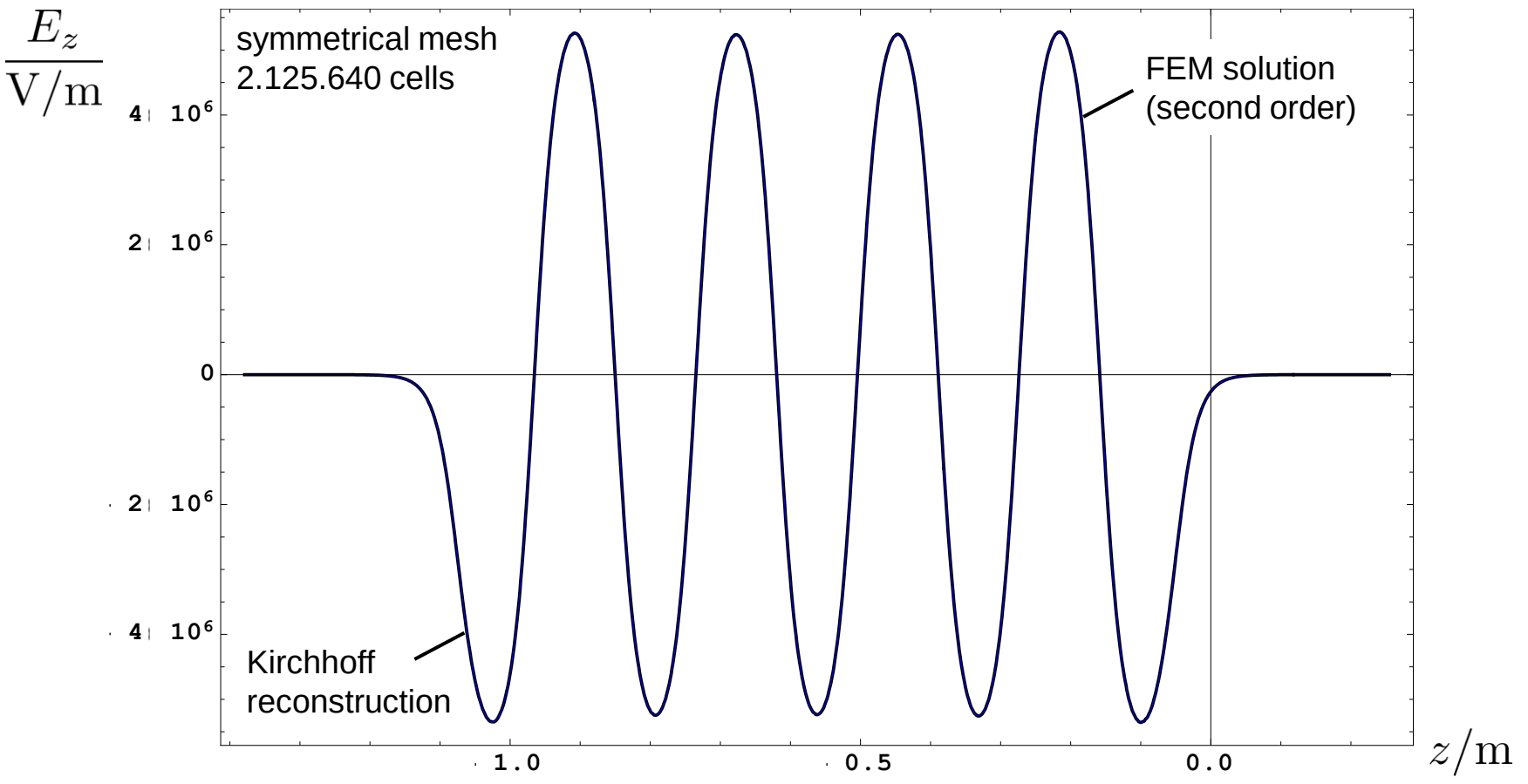

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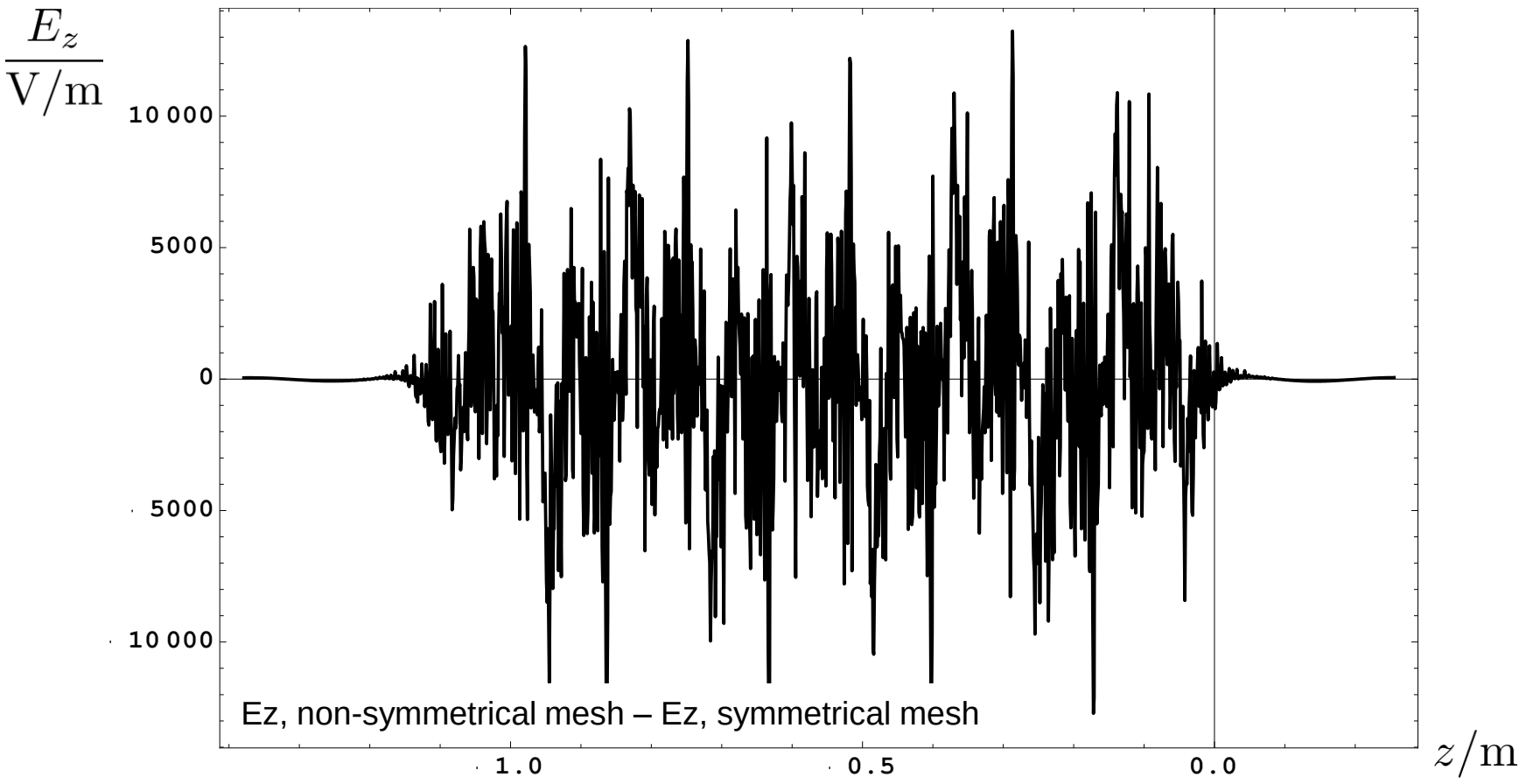

Numerical Modeling

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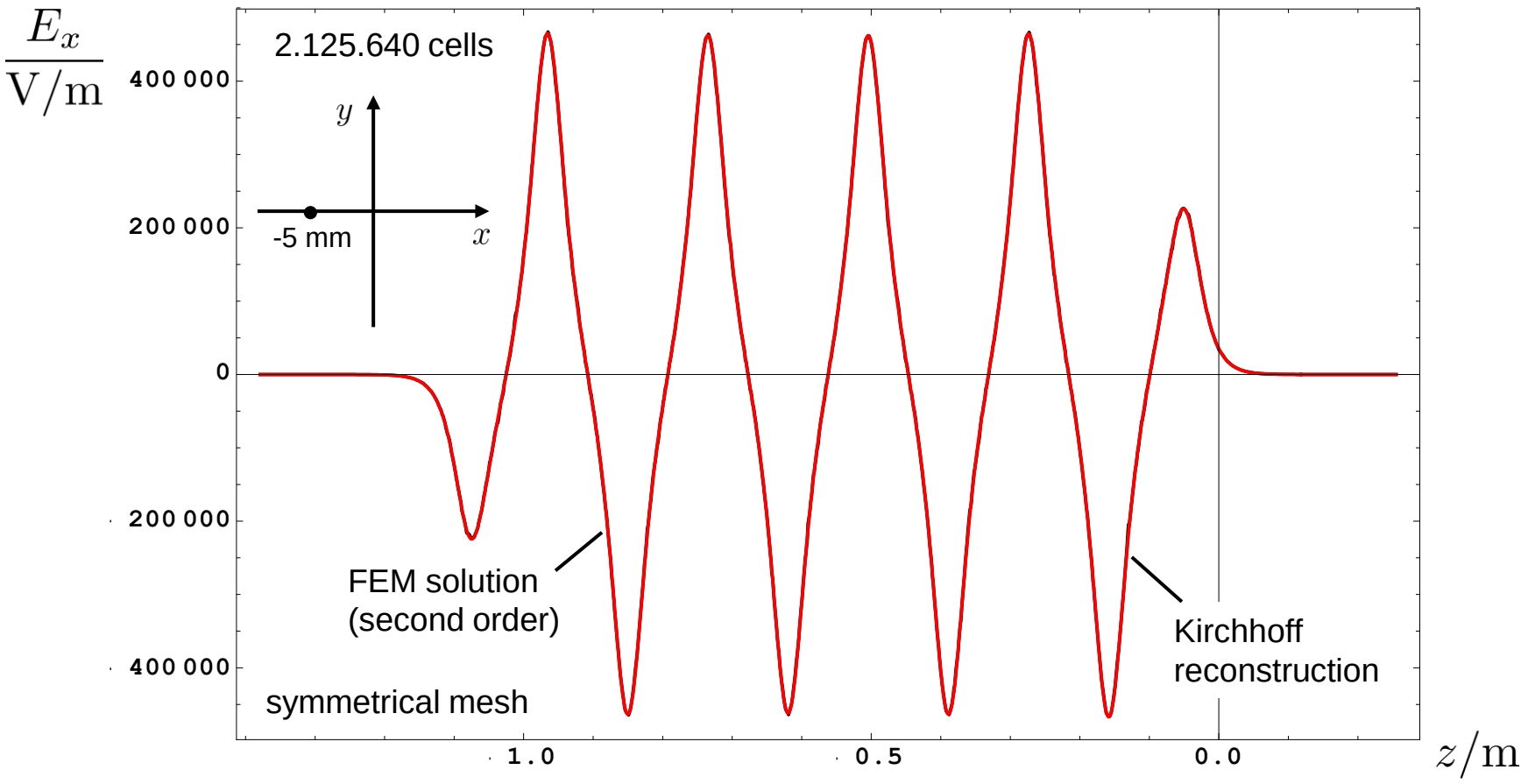

Numerical Modeling

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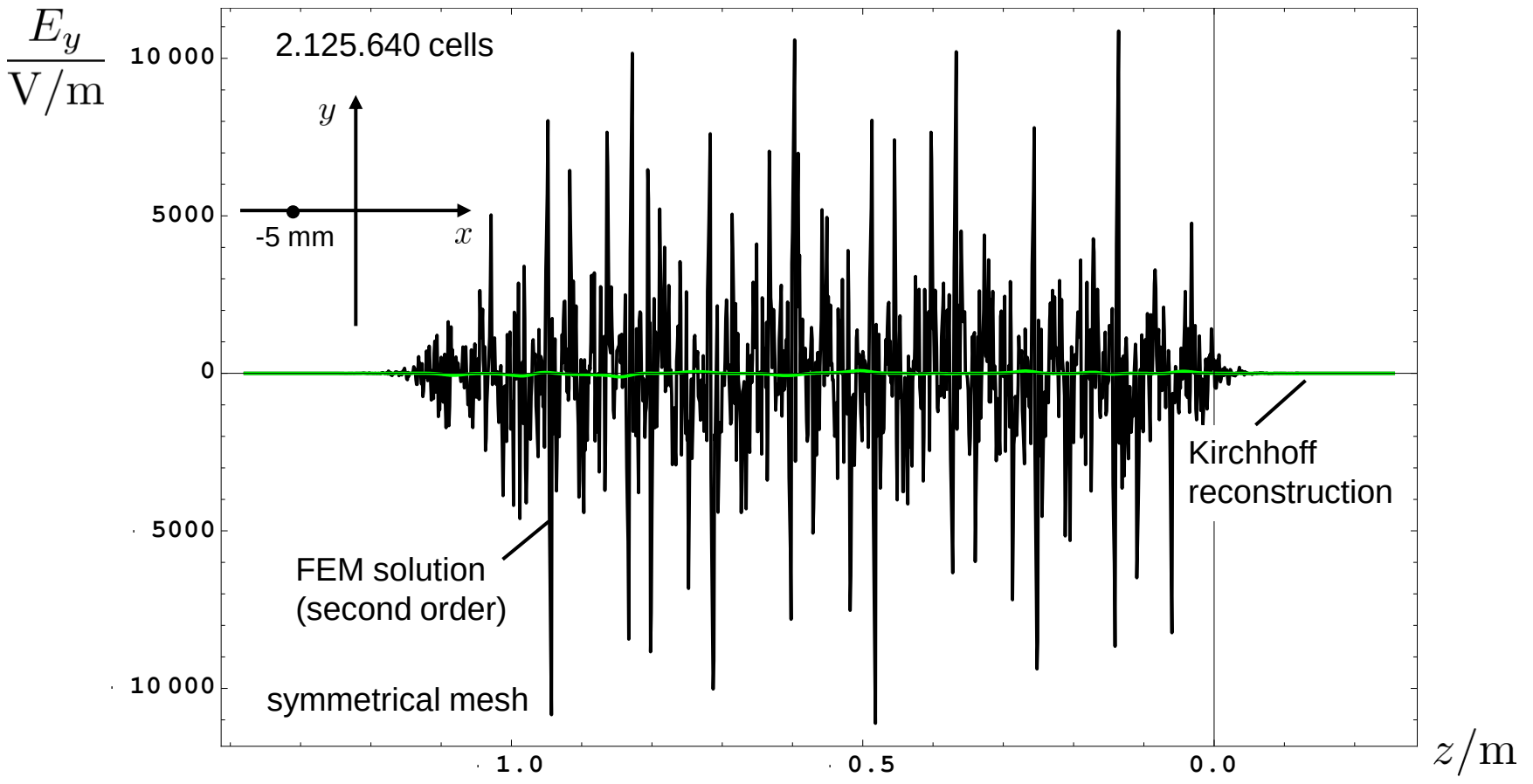

Numerical Modeling

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- Field reconstruction using the Kirchhoff integral
  - Current implementation demonstrates usability but implementation is too slow for particle tracking
    - Direct evaluation of the integral without taking the proximity of particles and source points into account
  - Alternatives include
    - Use hexahedral grid for field sampling (interpolation)
      Immediate usage of FEM solution on triangular artificial surface
    - Fast evaluation of the integral following the boundary element method approach for clusters of particles and source points

Summary

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- Eigenvalue calculation including ports
  - Second order field and geometry available
  - Ports are modeled with impedance boundary conditions (Only one mode per port is able to propagate)

- Extraction of field components for subsequent beam dynamics simulation
  - Kirchhoff integral provides a promising alternative to the direct evaluation of the FEM solution
  - For fast field calculation in arbitrary observation points the evaluation of the Kirchhoff integral is nontrivial