Numerical Calculation of Electromagnetic Fields in Acceleration Cavities Under Precise Consideration of Coupler Structures

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Outline

- Theoretical Background
- Computation of Eigenmodes and Post-Processing
- Comparison of the Results with other Literaturs
- Conclusion

Theoretical Background

Fundamental input coupler, higher order mode couplers and beam tubes

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Lossy acceleration structure: Quality factor $Q < \infty$

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Complex-valued finite element eigenmode analysis

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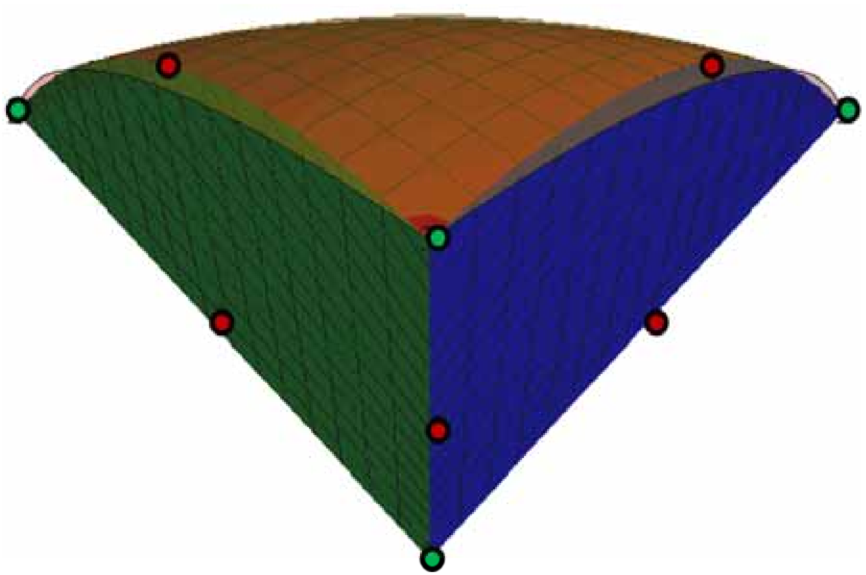
Complex angular resonance frequency: $\underline{\omega} = \omega + j\alpha$

$$Q = \frac{\omega}{2\alpha}$$

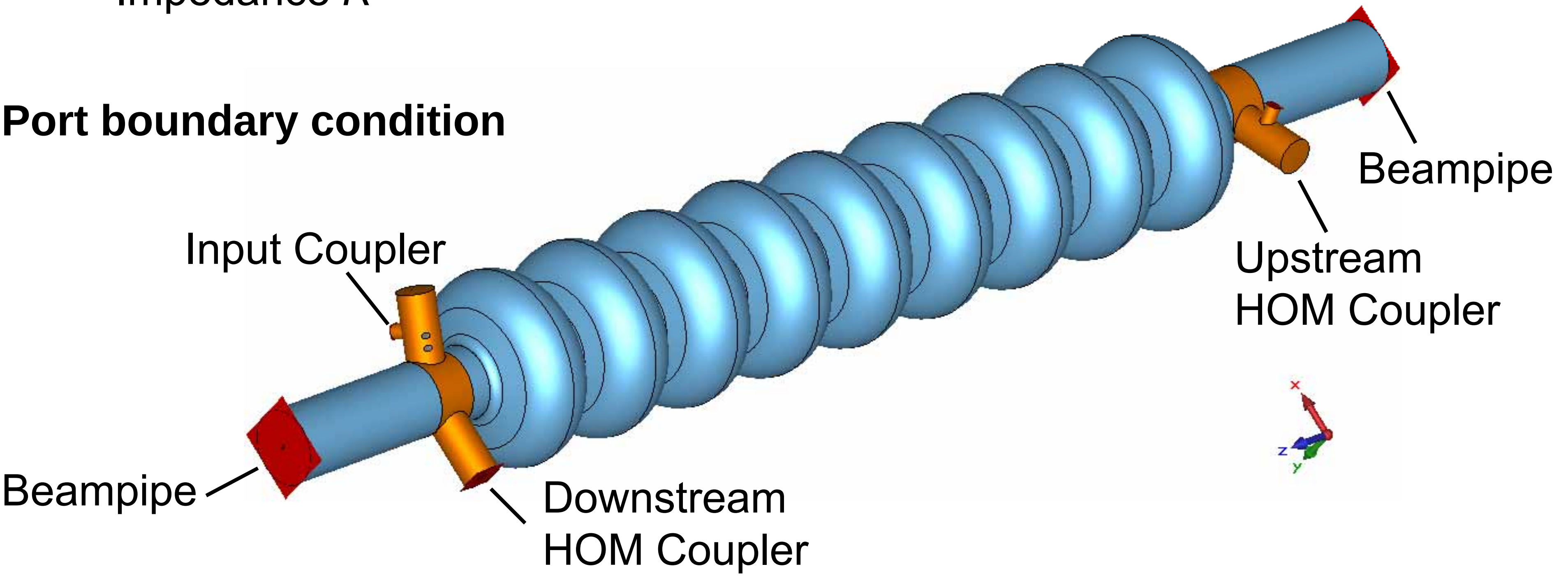
Theoretical Background

- Tetrahedral grids and higher order curvilinear elements can satisfy demand for high precision modeling (Contours of the elliptical cavity).
- The simulation is run on a distributed memory architecture using the MPI parallelization strategy.



Computation of Eigenmodes and Post-Processing

- TESLA 1.3 GHz nine-cell accelerating cavity (TESLA report at DESY)
  - Resonance frequency *f*
  - Quality factor *Q*
  - Field distribution
  - Shunt impedance *R/Q*
  - Impedance *R*

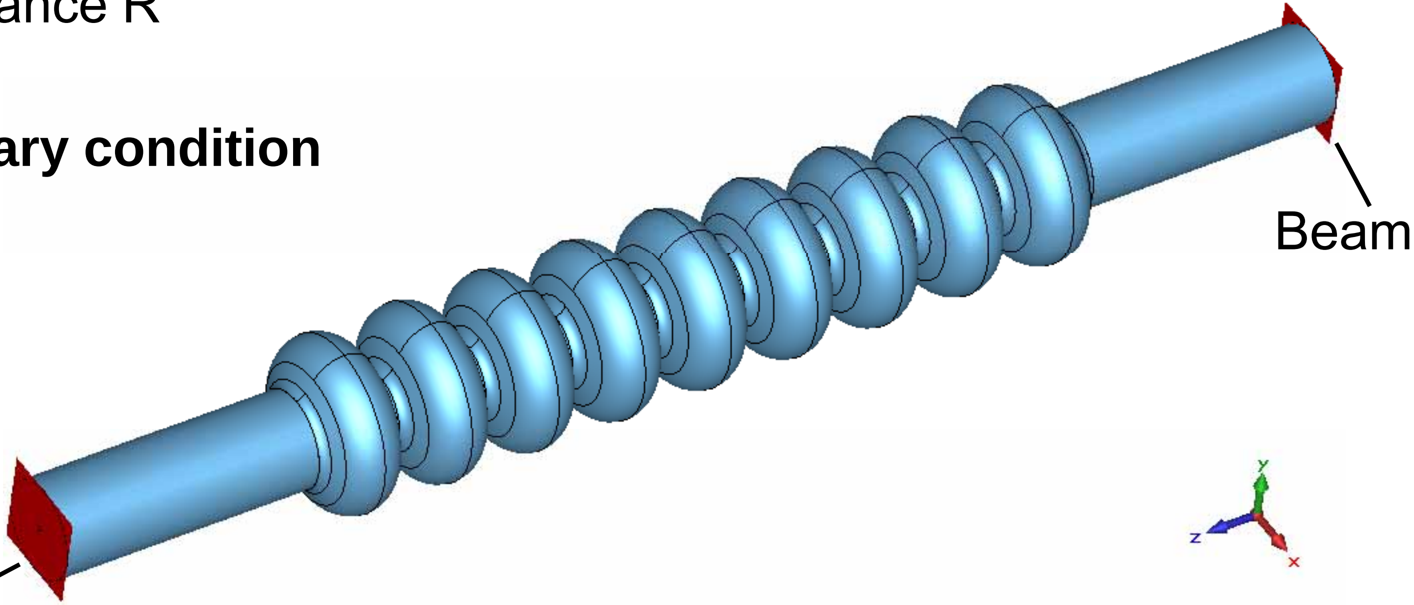


Port boundary condition

Computation of Eigenmodes and Post-Processing

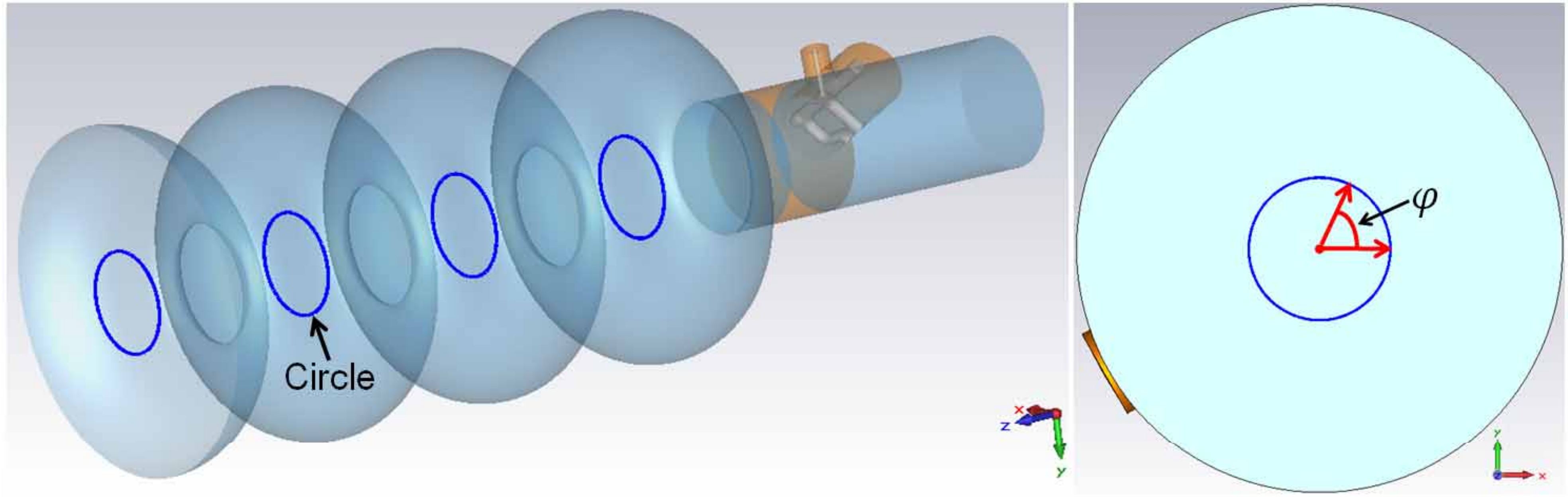
- The third harmonic nine-cell cavity (3.9 GHz)
  - Resonance frequency *f*
  - Quality factor *Q*
  - Field distribution
  - Shunt impedance *R/Q*
  - Impedance R

Port boundary condition



Computation of Eigenmodes and Post-Processing

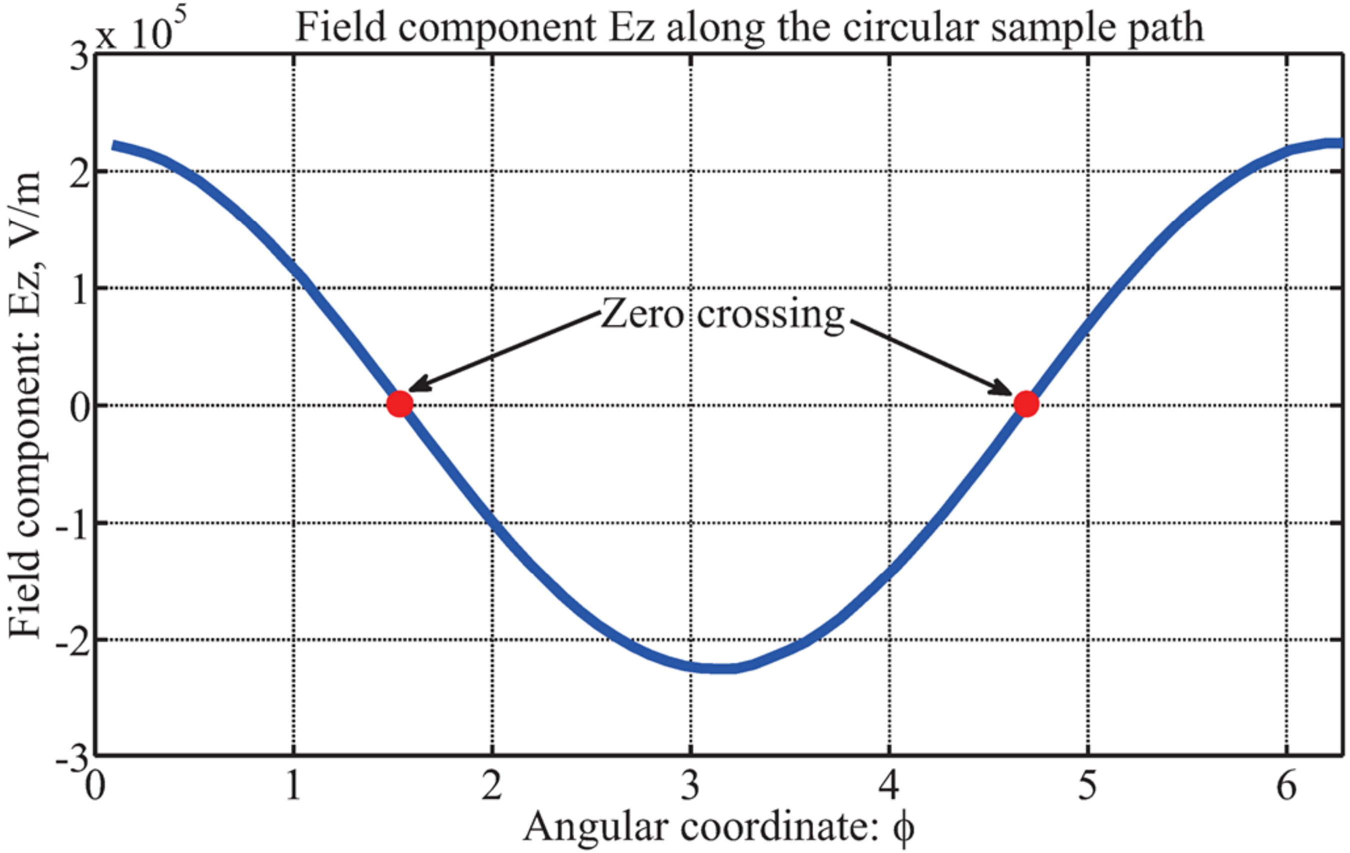
- Automatic identification of eigenmode type



Sample the longitudinal E-Field component E_z of a eigenmode along a circle in the individual cell.

Computation of Eigenmodes and Post-Processing

- Automatic identification of eigenmode type



For example:
Two zero crossings in the right plot.
=> Dipole mode.

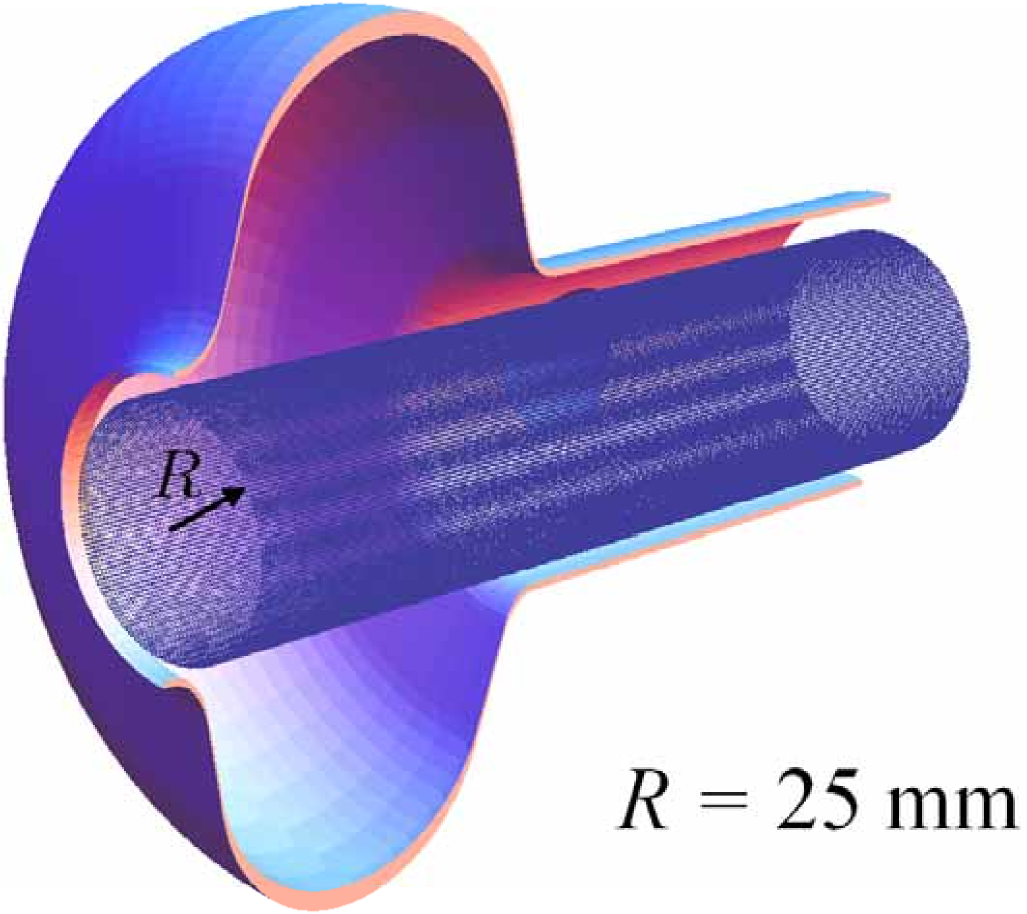
According to the number of zero crossings for E_z , the mode type can be identified automatically.

Computation of Eigenmodes and Post-Processing

- Field smoothing using the Kirchhoff’s integral

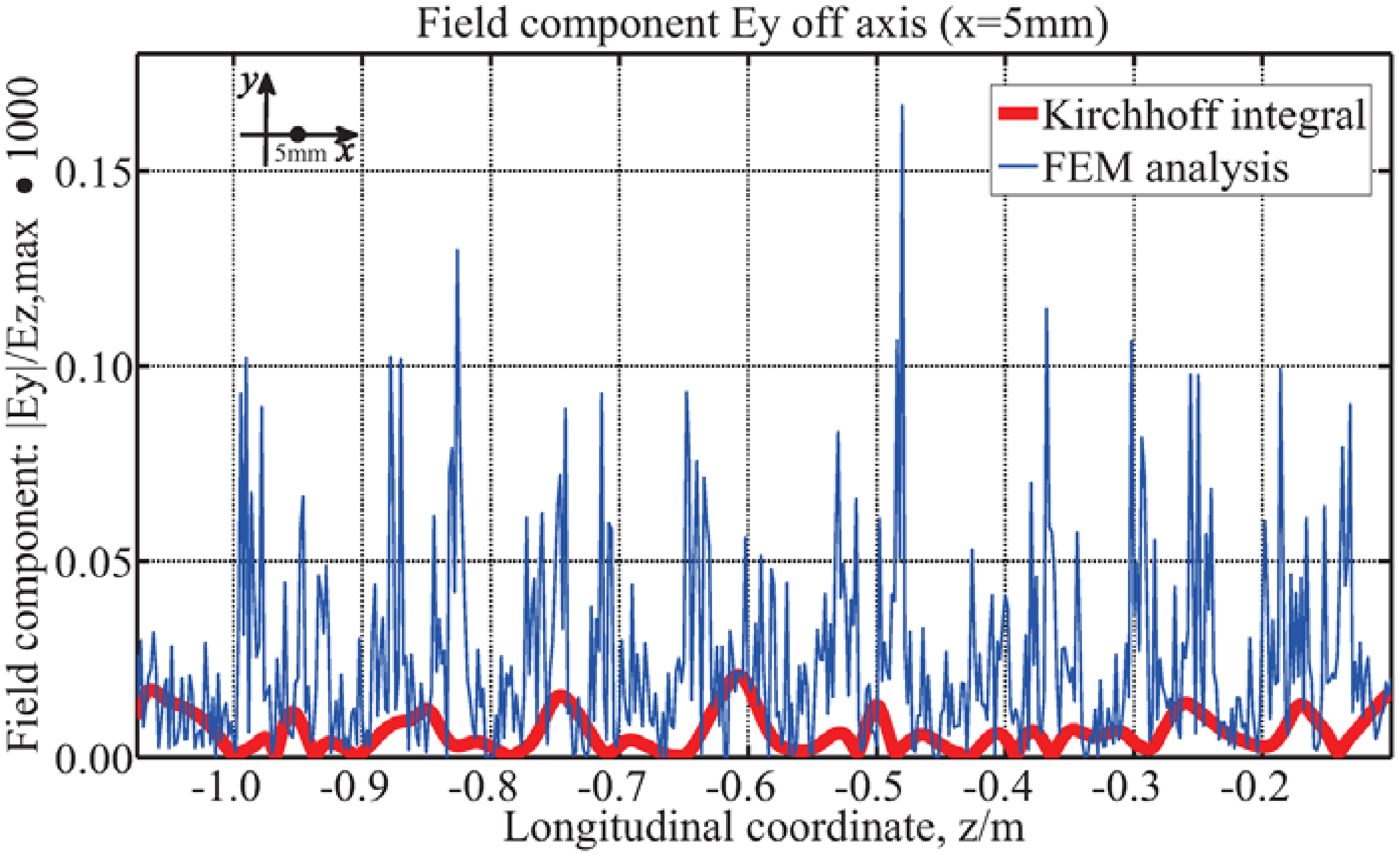
  − Field components inside a closed surface can be determined once the surface field components are available.

  ⇒ Precise shunt impedance of eigenmode.



Computation of Eigenmodes and Post-Processing

- Field smoothing using the Kirchhoff's integral



  - Transverse field components are more smooth than the field components from standard FEM analysis

Comparison of the Results with other Literatures

- Comparison of the frequency and shunt impedance R/Q for eigenmodes with other literatures

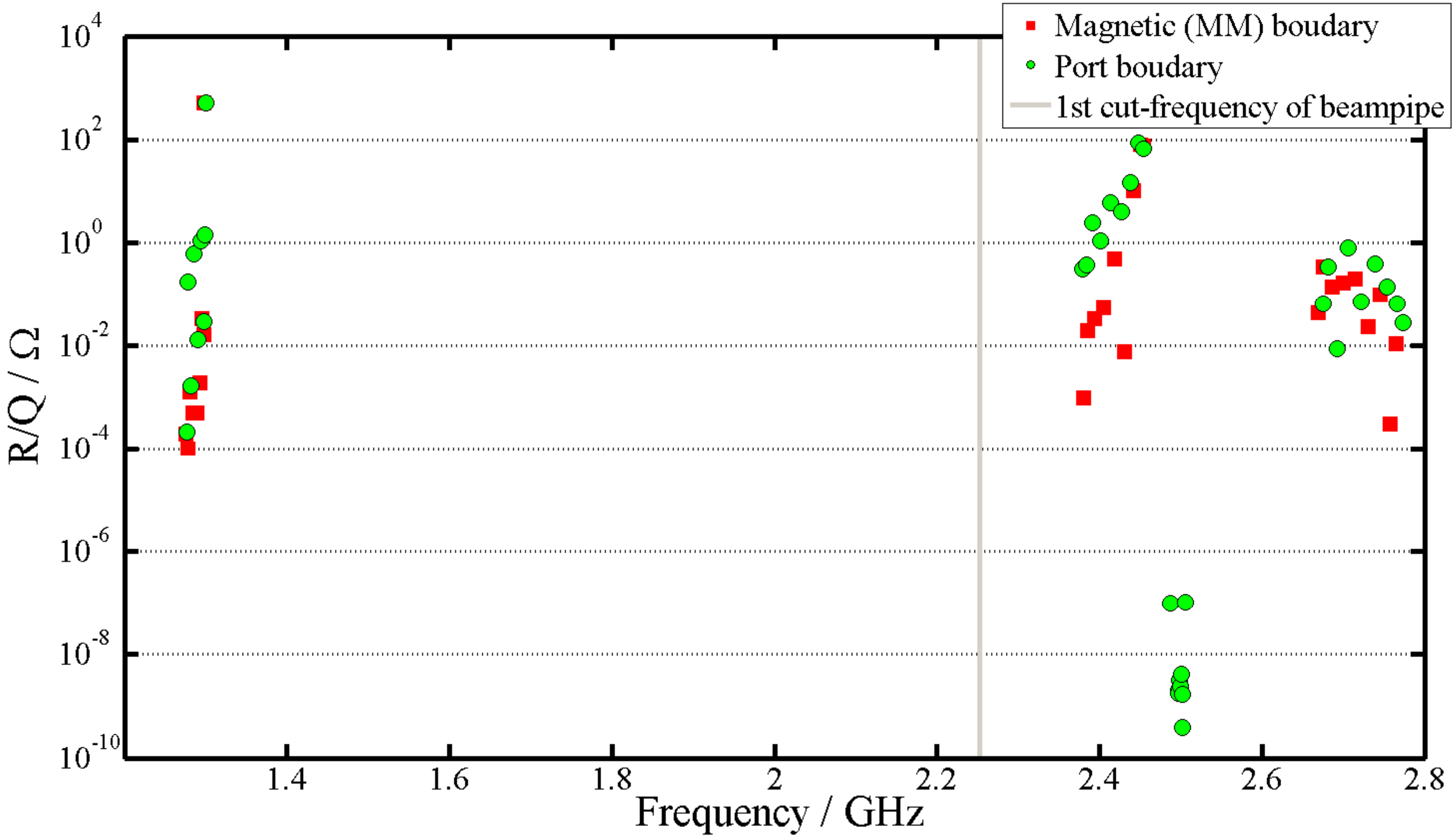
$$\frac{R^{(m)}}{Q} = \frac{1}{r^{2m}} \frac{2k^{(m)}(r)}{\omega}$$

$$\text{with } k^{m}(r) = \frac{\left|V_L{}^{(m)}(r)\right|^2}{4U^{(m)}}$$ [1]

[1] TESLA 2001-33 September 2001: Monopole, Dipole and Quadrupole Passbands of the TESLA 9-cell Cavity, R. Wanzenberg

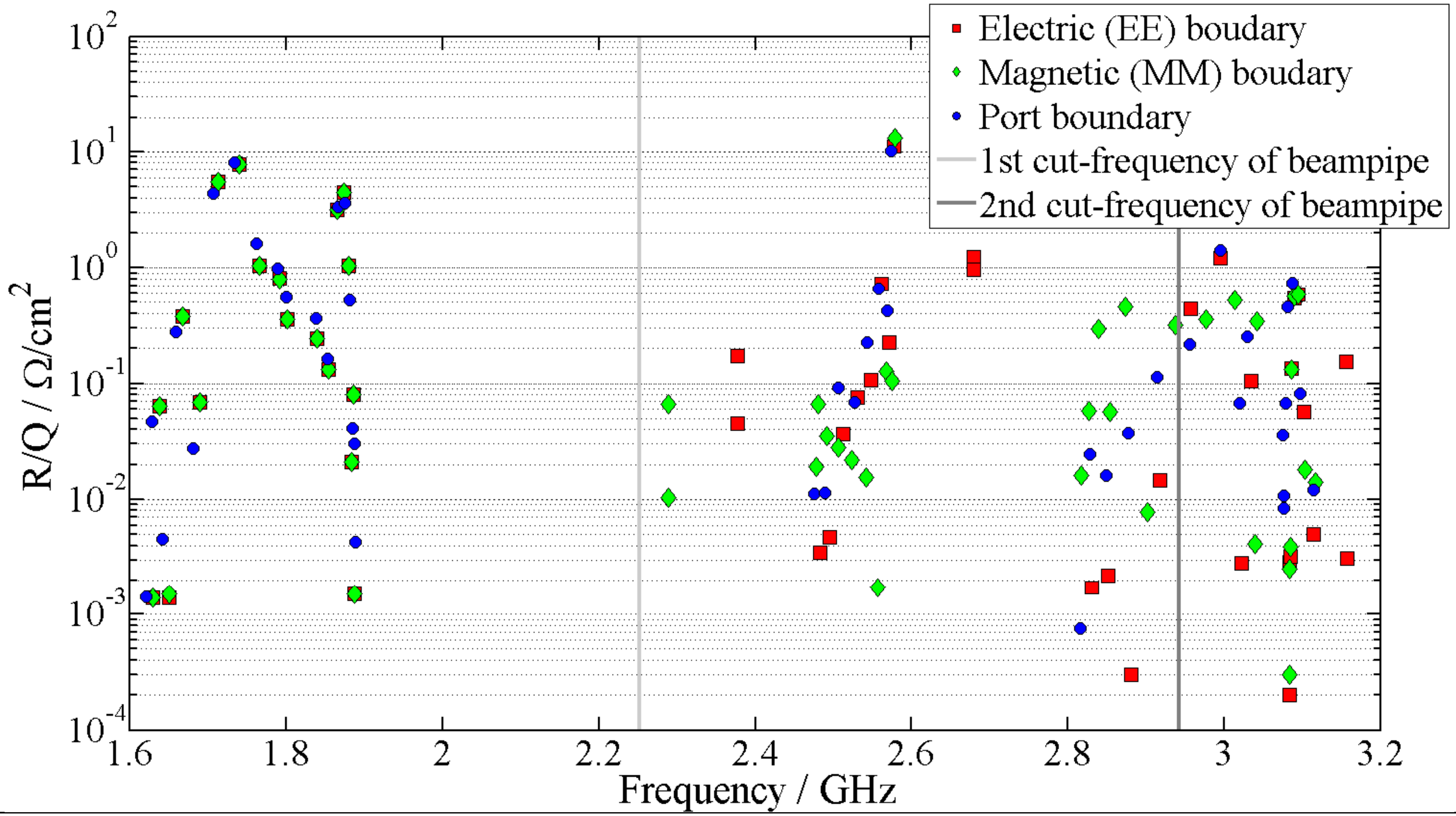
Comparison of the Results with other Literatures

- TESLA 1.3 GHz nine-cell accelerating cavity (TESLA 2001-33)
  - R/Q of the monopole modes



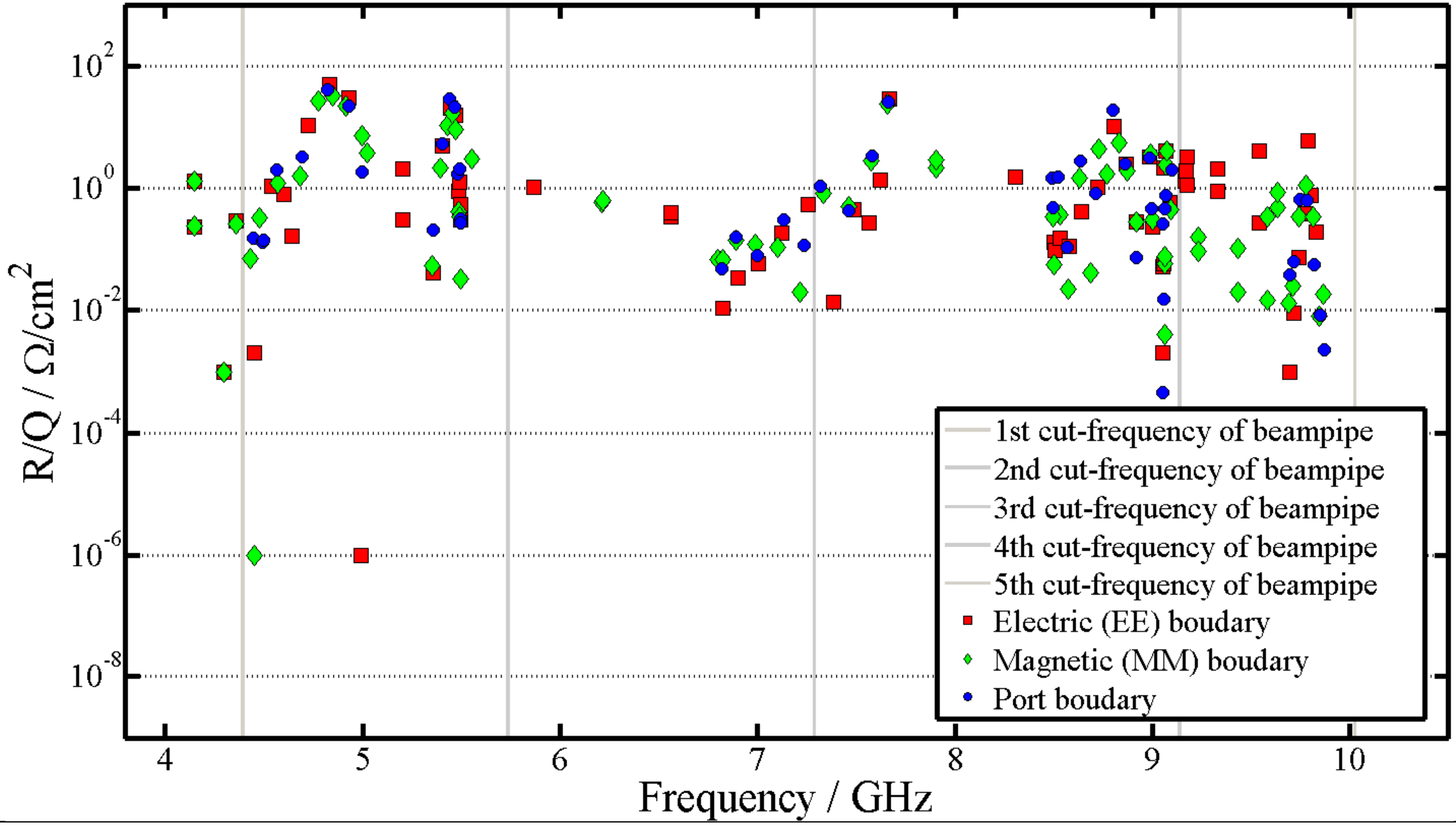
Comparison of the Results with other Literatures

- TESLA 1.3 GHz nine-cell accelerating cavity (TESLA 2001-33)
  - R/Q of the dipole modes



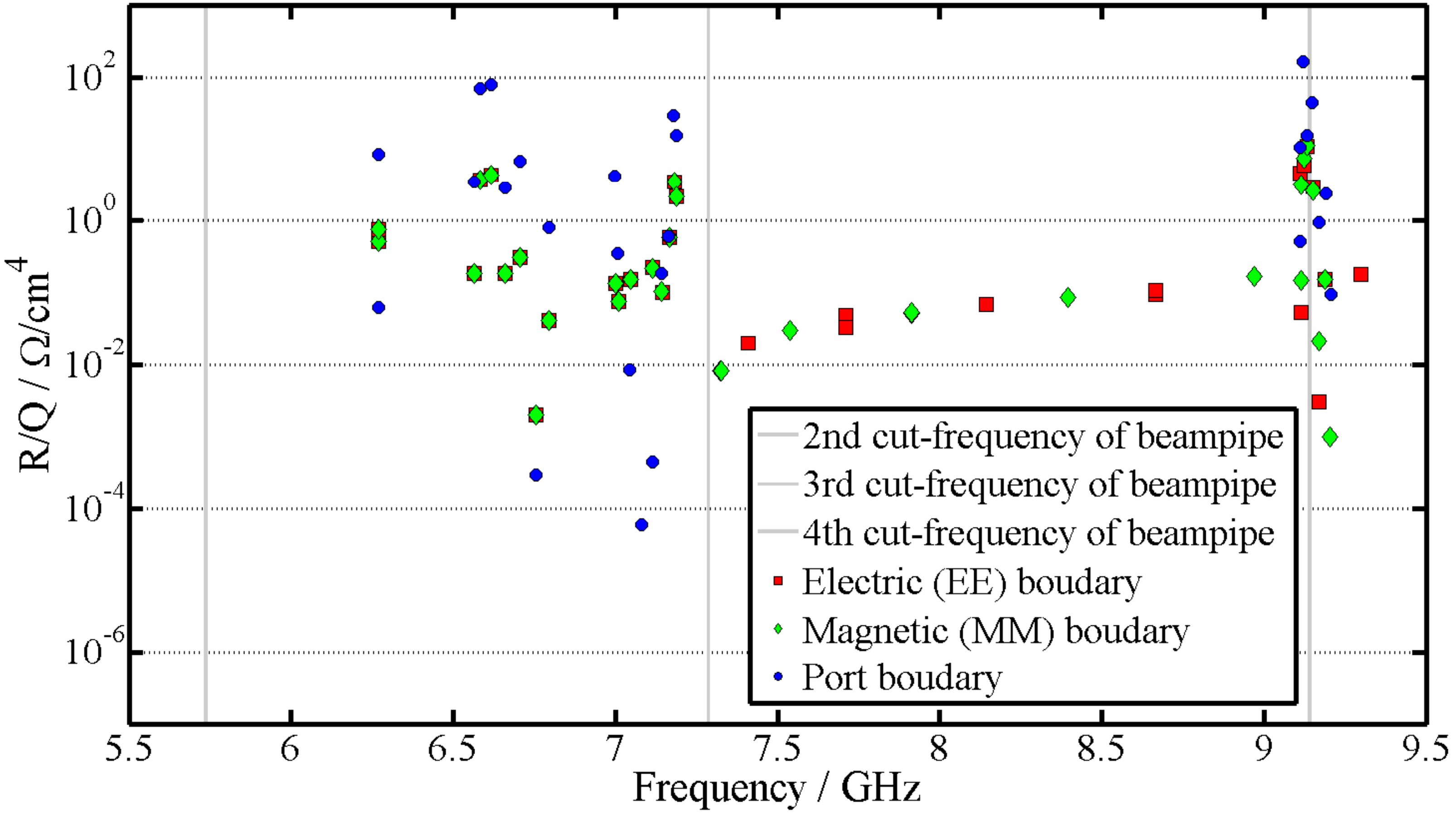
Comparison of the Results with other Literatures

- The third harmonic nine-cell cavity (3.9 GHz) (DESY-12-101*)
  - R/Q of the dipole modes



Comparison of the Results with other Literatures

- The third harmonic nine-cell cavity (3.9 GHz) (DESY-12-101*)
  - R/Q of the quadrupole modes



* Eigenmode Simulations of Third Harmonic Superconducting Accelerating Cavities for FLASH and the European XFEL- Zhang, Pei *et al.* arXiv:1206.2782

Conclusion

- A robust parallel eigenmode solver on the basis of complex-valued finite element analysis has been successfully applied to analyze the electromagnetic field inside a lossy TESLA 1.3 GHz accelerating cavity and a third harmonic nine-cell cavity (3.9 GHz).
- The electromagnetic field inside the cavity can be smoothed on a physically motivated basis using Kirchhoff's integral theorem.
- Custom-made post-processing routines have been developed to ease the necessary post-processing steps.

Thank you for your attention!

Merry Christmas!!