RF Emission Spectra in Laser-Plasma Acceleration of Protons

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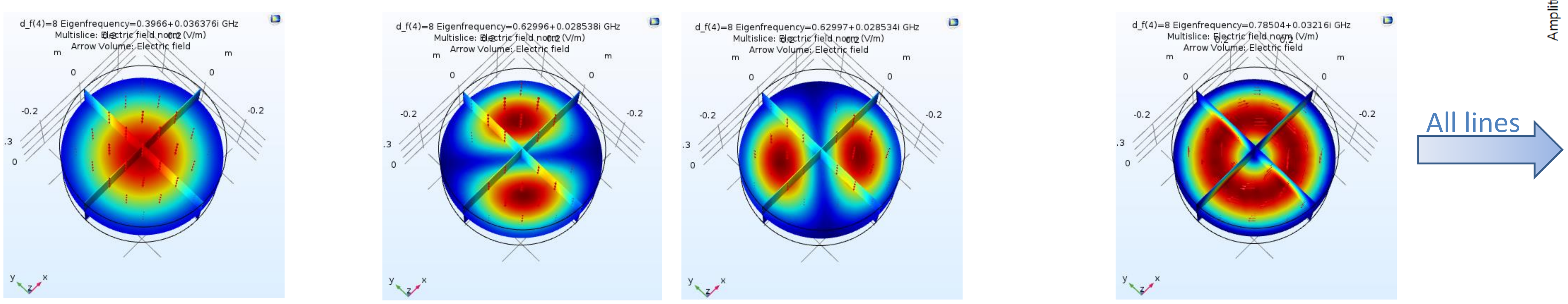
Background and objectives

The acceleration of protons and ions by highly intense laser pulses has become a field of increasingly active research. One of the phenomena commonly observed in laser-plasma interactions is the emission of a strong electromagnetic pulse (EMP). At least three distinct sources of EMP have been described.[1] Their experimental identification may provide insight into details of plasma formation and evolution, but also for EMP suppression to prevent interference with delicate equipment. The present study is dedicated to one of these sources, the components of a laser-plasma experiment which may act as resonant cavities[3] and antennas after excitation by charged particles.

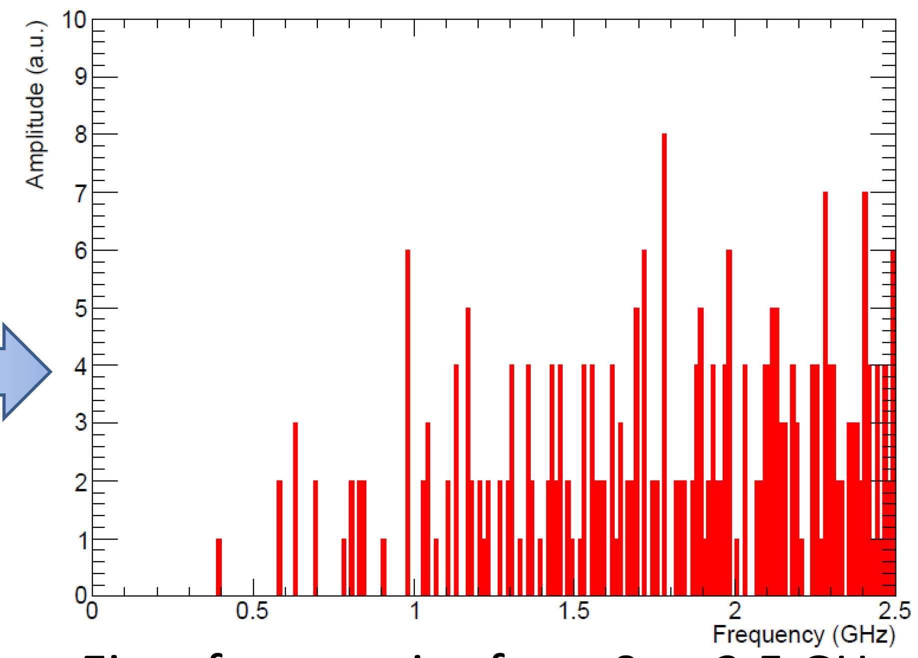
Theory and simulation

One major source of EMP is a cylindrical vacuum vessel of 60 cm diameter and 30 cm height. Similar to previous studies[4,5,6] its RF eigenmodes are simulated in COMSOL Multiphysics® (RF module) following a tutorial example[7] and the results are compared to analytical predictions for a symmetric cavity. Then other components of an experimental setup are included step by step to study their effects on the eigenfrequency spectra, including internal parts acting as microwave antennas[8]. Here we show three levels of increasingly complex geometry and the complete sets of eigenmodes up to 2.5 GHz.

1. Cylindrical chamber with glass cover

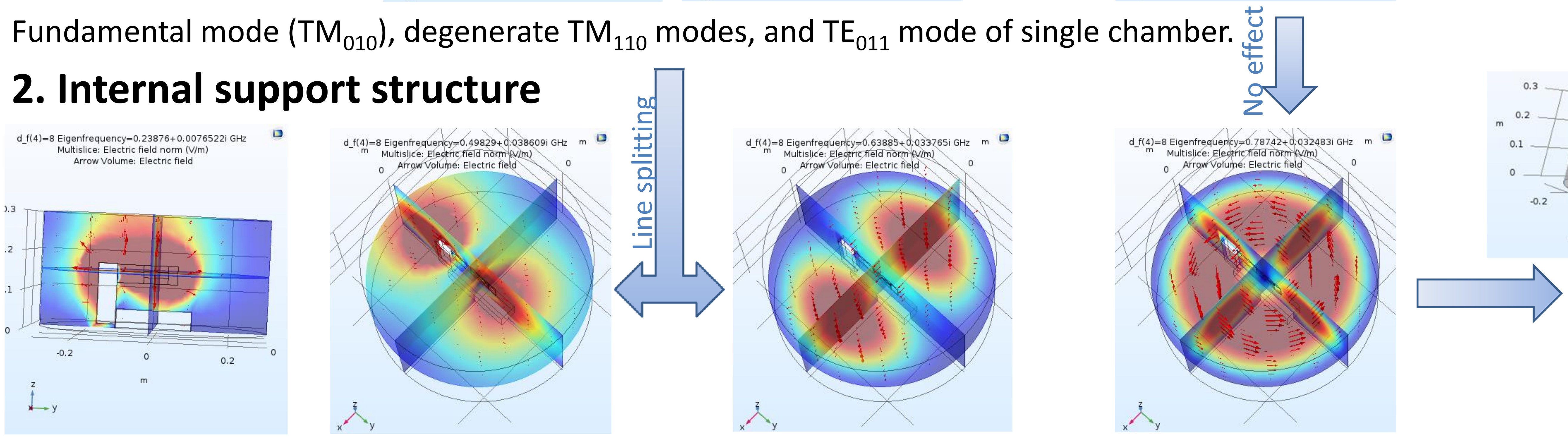


Fundamental mode (TM_{010}), degenerate TM_{110} modes, and TE_{011} mode of single chamber.

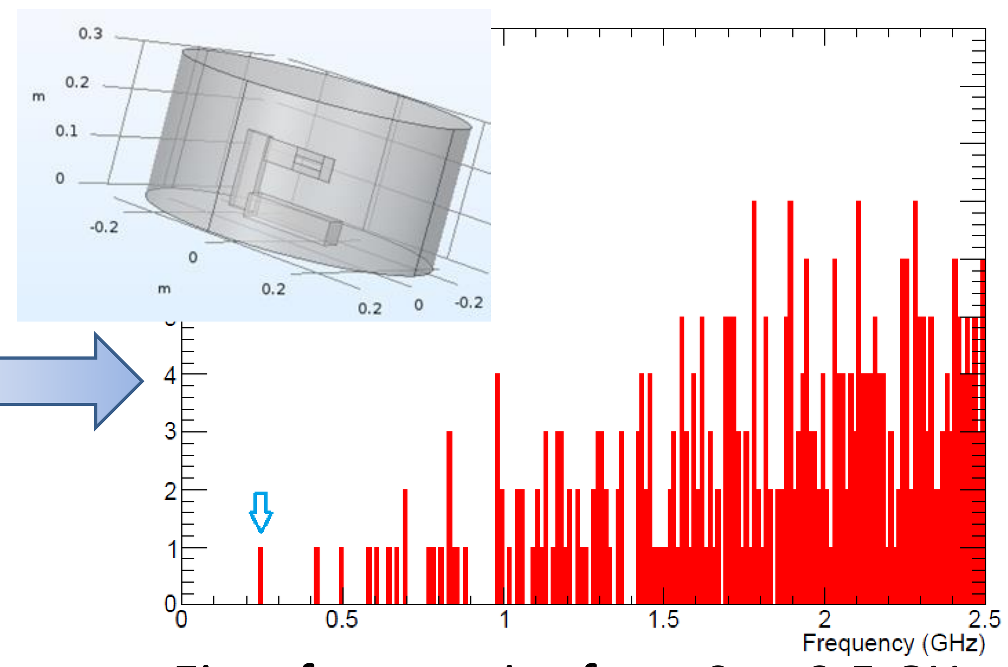


Eigenfrequencies from 0 to 2.5 GHz

2. Internal support structure

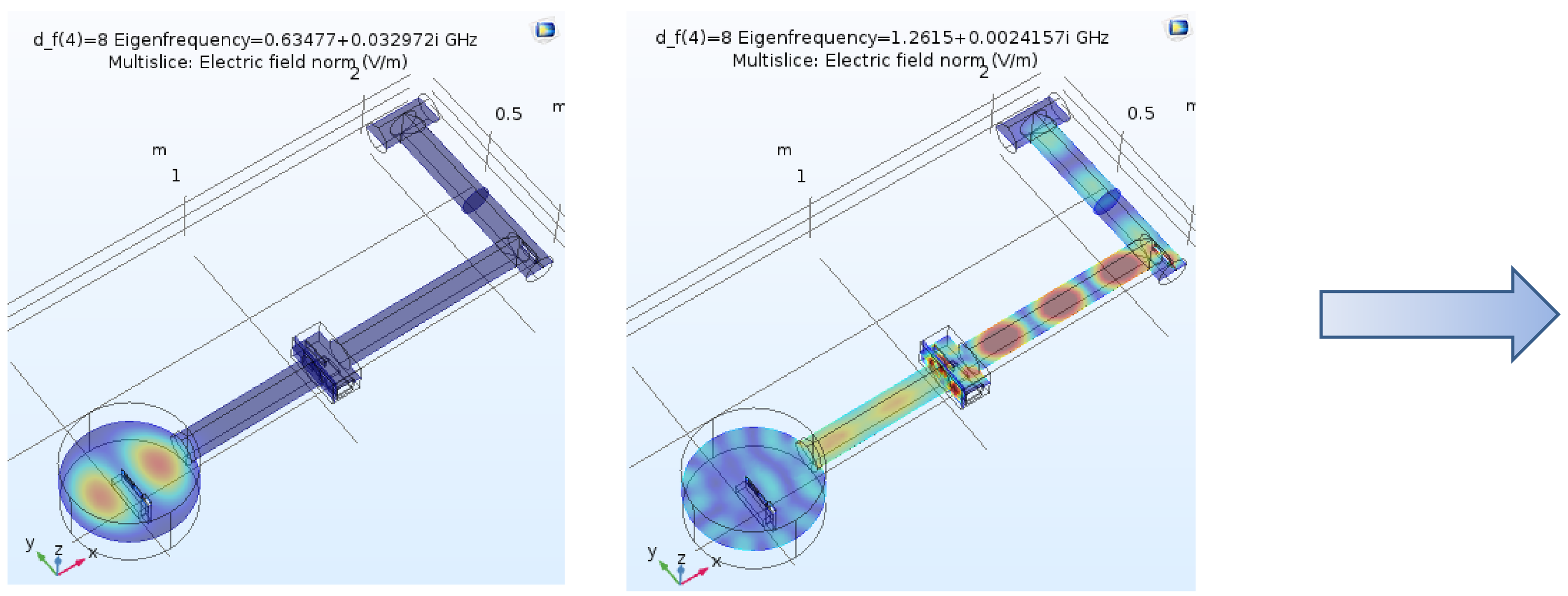


Additional line due to antenna, non-degenerate TM_{110} modes, and TE_{011} mode.

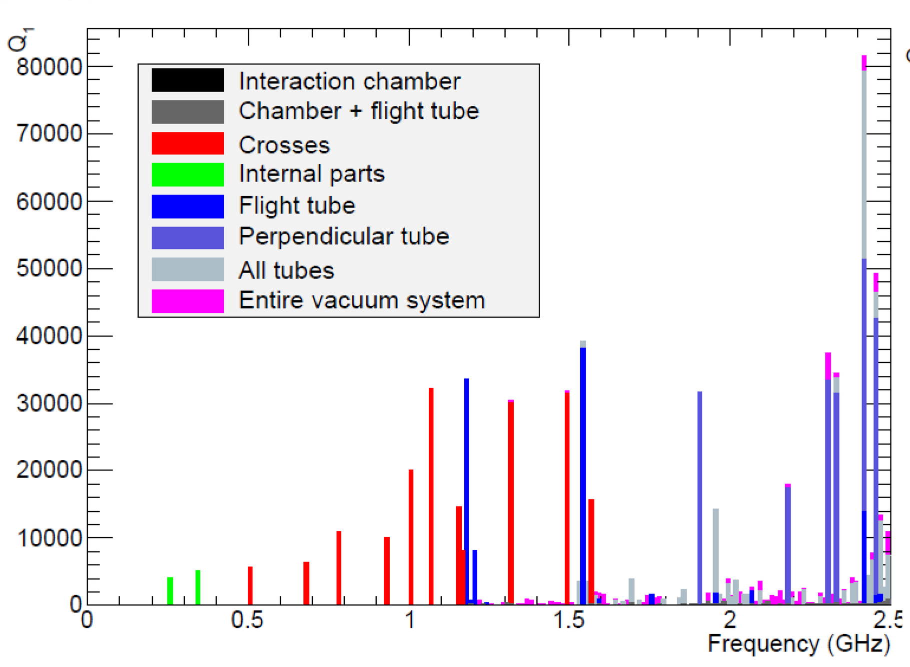


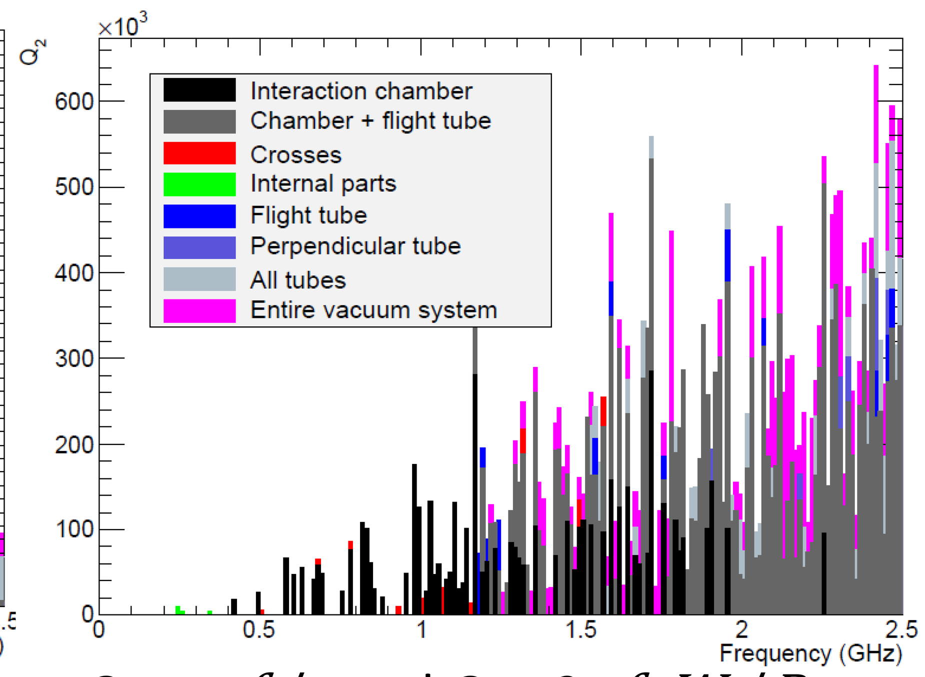
Eigenfrequencies from 0 to 2.5 GHz

3. Complete setup with vacuum tubes and internal parts



Resonances of individual components and coupled modes.





Eigenfrequencies weighted by Q-factors, $Q_1 = \pi f_0/\gamma$ and $Q_2 = 2\pi f_0\, W_t/P_d$.

Conclusions

About 550 eigenmodes are identified up to 2.5 GHz. The number of lines below 1 GHz is quite limited and this interval comprises signals from the inner "antennas". The next challenge consists of identifying simulated lines with those from experiments as well as the excitation strength of individual modes. The Q-factors alone may not indicate the corresponding amplitudes of single frequencies; instead, the response of the setup to charged particle deposition should be simulated.

References

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7. COMSOL Multiphysics Application gallery 9618, "Computing Q-factors and resonant frequencies of cavity resonators"
8. COMSOL Multiphysics Application gallery 8715, "Dipole antenna"