Pickup-Signal Calculation for a 1.6 Cell Superconducting RF Gun

TECHNISCHE UNIVERSITÄT DARMSTADT

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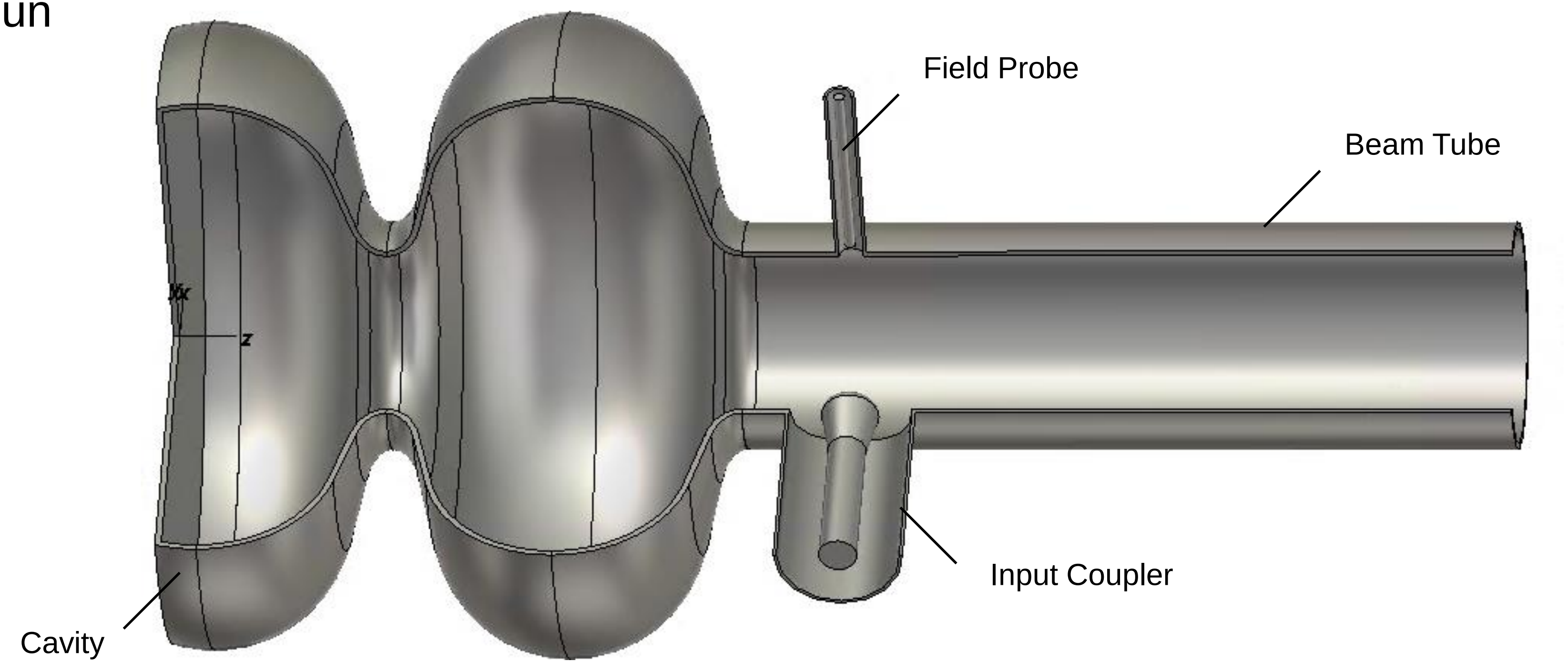
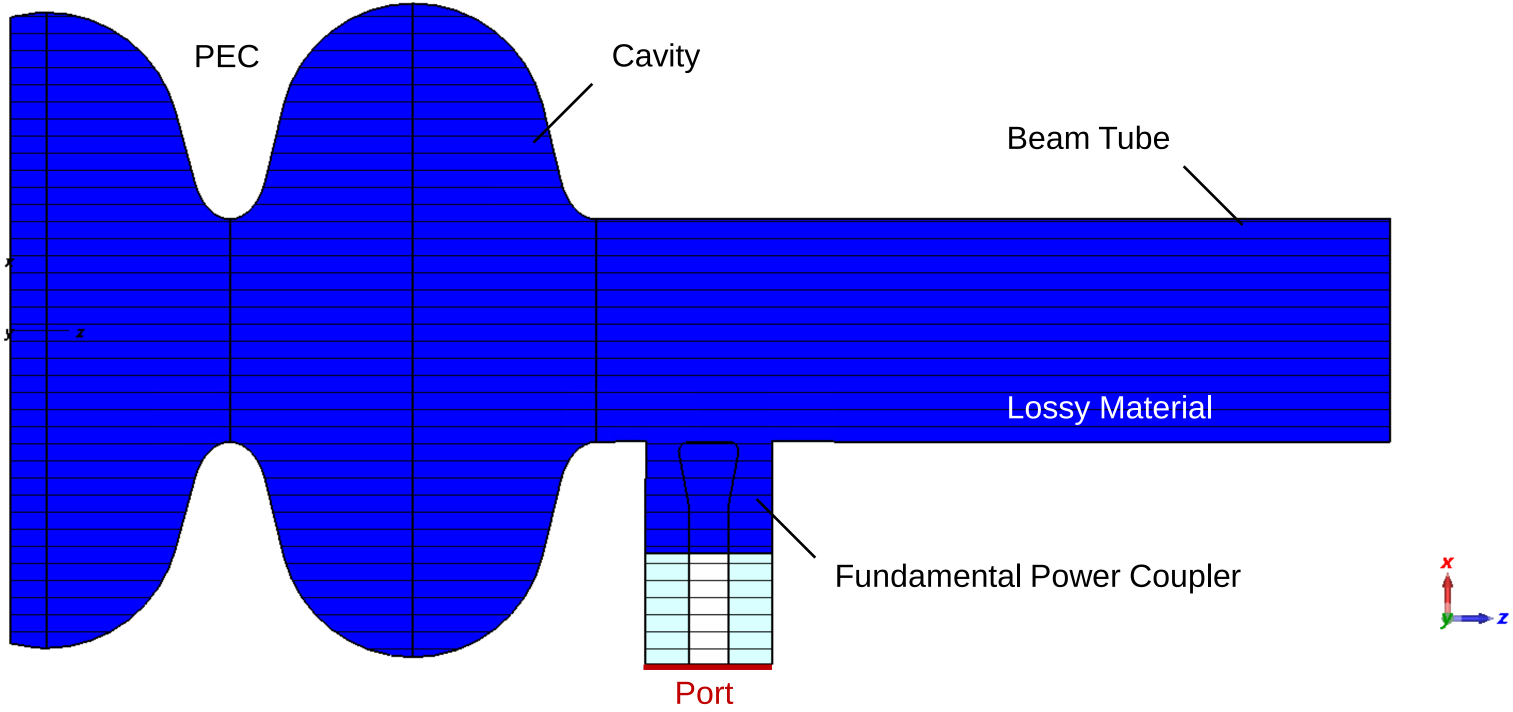
Motivation

RF Gun



Numerical Modeling

RF Gun



Numerical Modeling

Maxwell Equations in Frequency Domain

$$\mathrm{curl}\underline{\vec{H}} = \quad i\omega\,\varepsilon\,\underline{\vec{E}}$$
$$\mathrm{curl}\underline{\vec{E}} = -i\omega\,\mu\,\underline{\vec{H}}$$

external excitation

$$\mathrm{curl}\underline{\vec{H}} = \quad i\underline{\omega}\,\varepsilon\,\underline{\vec{E}}$$
$$\mathrm{curl}\underline{\vec{E}} = -i\underline{\omega}\,\mu\,\underline{\vec{H}}$$

$$\underline{\omega} = \omega - i\,\frac{\omega}{2Q} = \omega\left(1 - i\,\frac{1}{2Q}\right) = \omega\,\underline{a}$$

$$\tan\delta = \frac{1}{2Q}$$

modified material

$$\underline{\omega}\,\varepsilon = \omega\,\underline{a}\,\varepsilon = \omega\,\underline{\varepsilon}$$
$$\underline{\omega}\,\mu = \omega\,\underline{a}\,\mu = \omega\,\underline{\mu}$$

$$Z = \sqrt{\frac{\underline{\mu}}{\underline{\varepsilon}}} = \sqrt{\frac{\mu}{\varepsilon}}$$

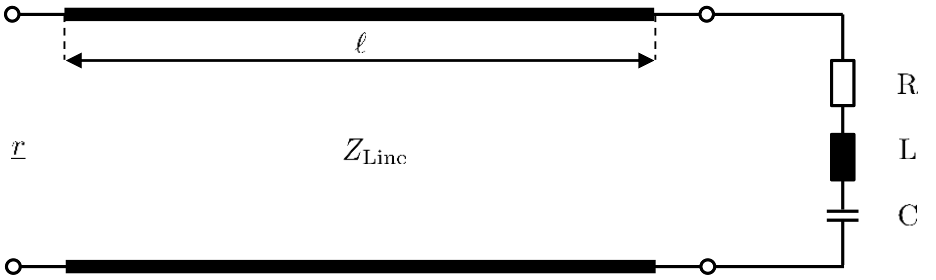
$$\underline{\varepsilon} = \varepsilon\,\underline{a}$$
$$\underline{\mu} = \mu\,\underline{a}$$

Numerical Modeling

RF Gun

- Lumped Element Model

$$Z_{\text{Cavity}} = R + i\omega L + \frac{1}{i\omega C}$$



$$\underline{r} = \frac{Z_{\text{Cavity}} - Z_{\text{Line}}}{Z_{\text{Cavity}} + Z_{\text{Line}}}$$

$$= \frac{1 - (\omega/\omega_0)^2 + i\,2/\Delta Q\,\omega/\omega_0}{1 - (\omega/\omega_0)^2 + i\,(2/Q_0 - 2/\Delta Q)\,\omega/\omega_0}$$

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$\frac{1}{Q_0} = \omega_0 RC$$

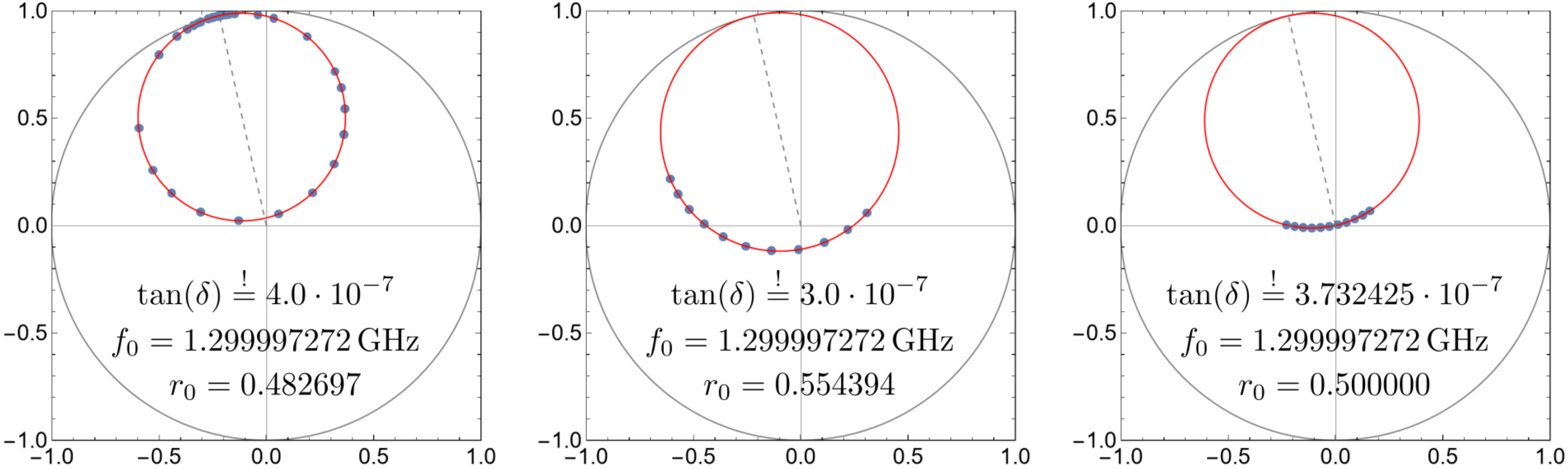
$$\frac{1}{\Delta Q} = \frac{1}{2}\omega_0 (R - Z_{\text{Line}}) C$$

Numerical Results

RF Gun

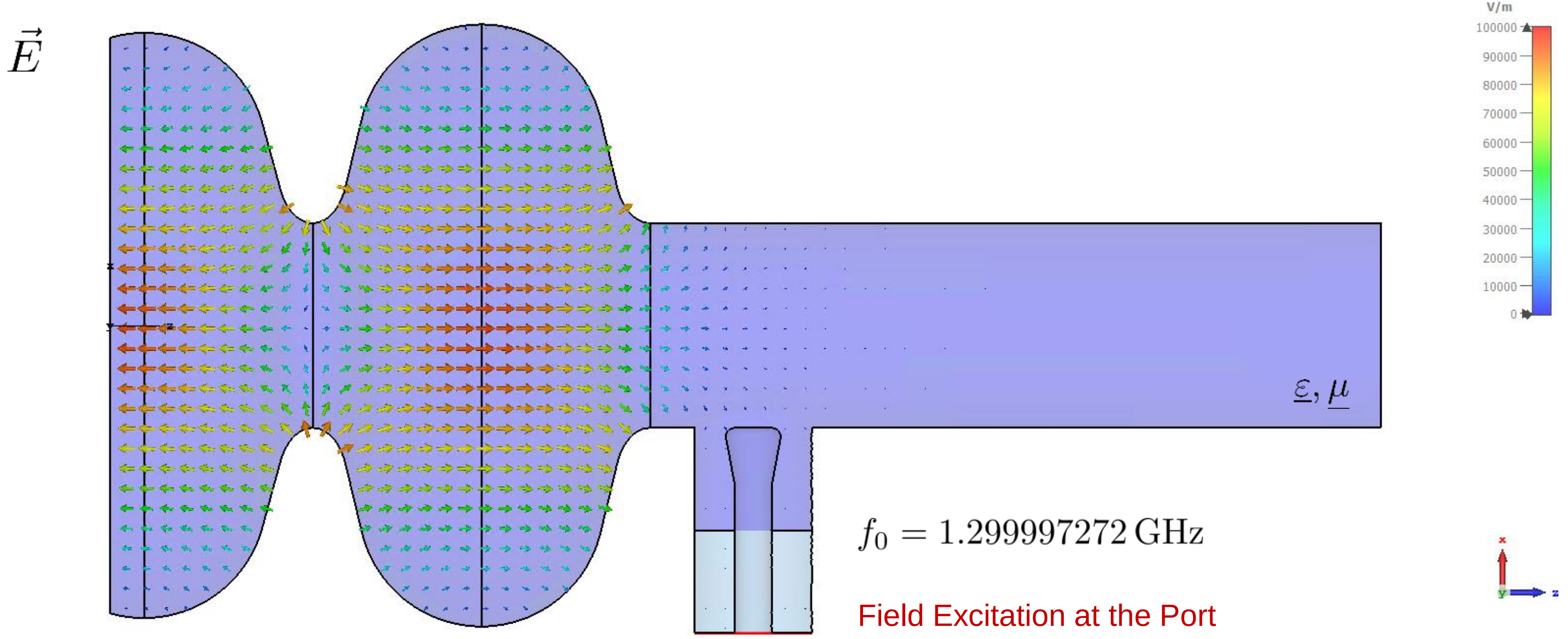
- Reflection Coefficient in the Complex Plane

Dots: 3D Calculation
Line: Network Model Fit



Numerical Results

Distribution of the Electromagnetic Field



$$f_0 = 1.299997272\,\mathrm{GHz}$$

Field Excitation at the Port

Numerical Results

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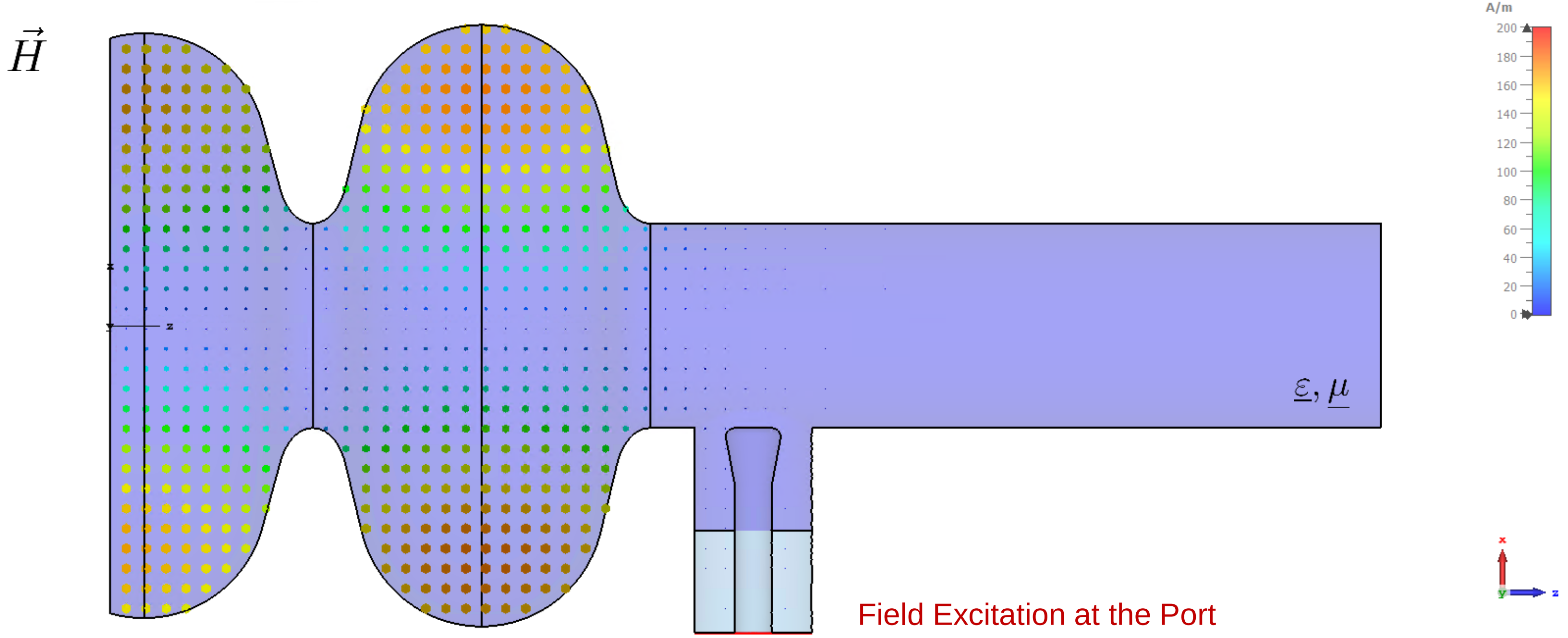
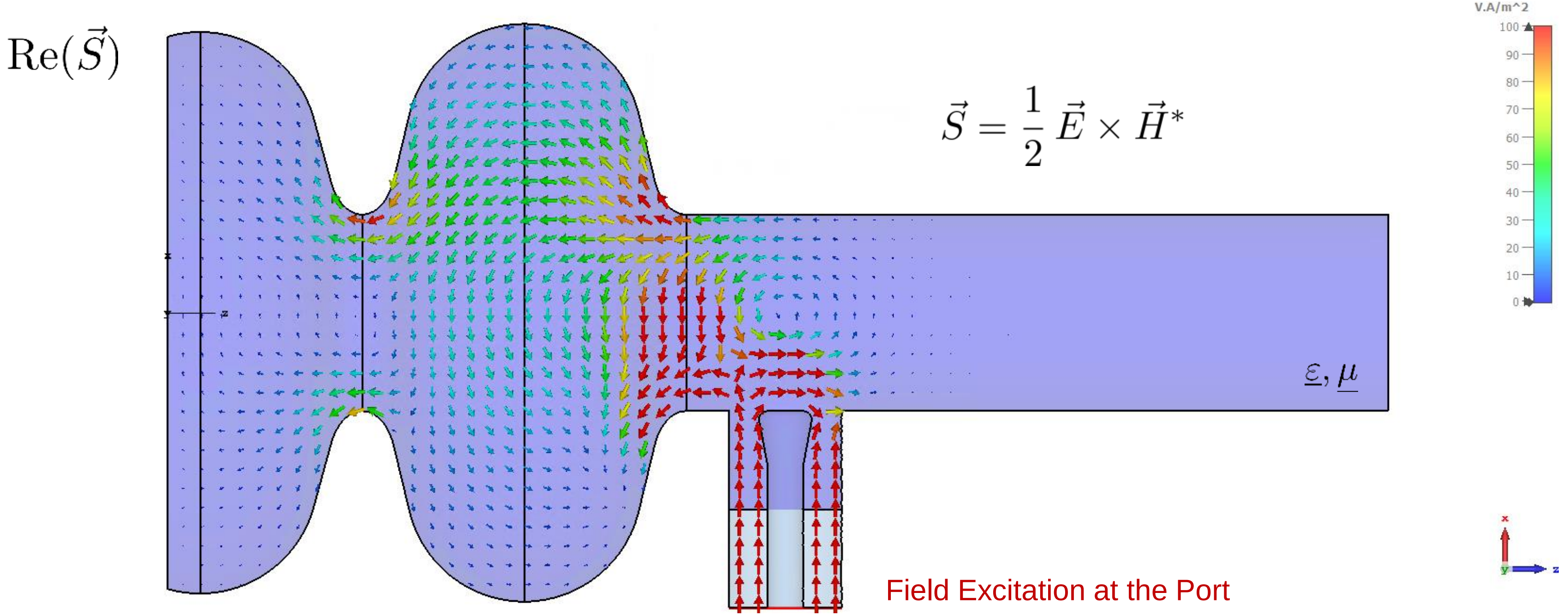
Distribution of the Electromagnetic Field



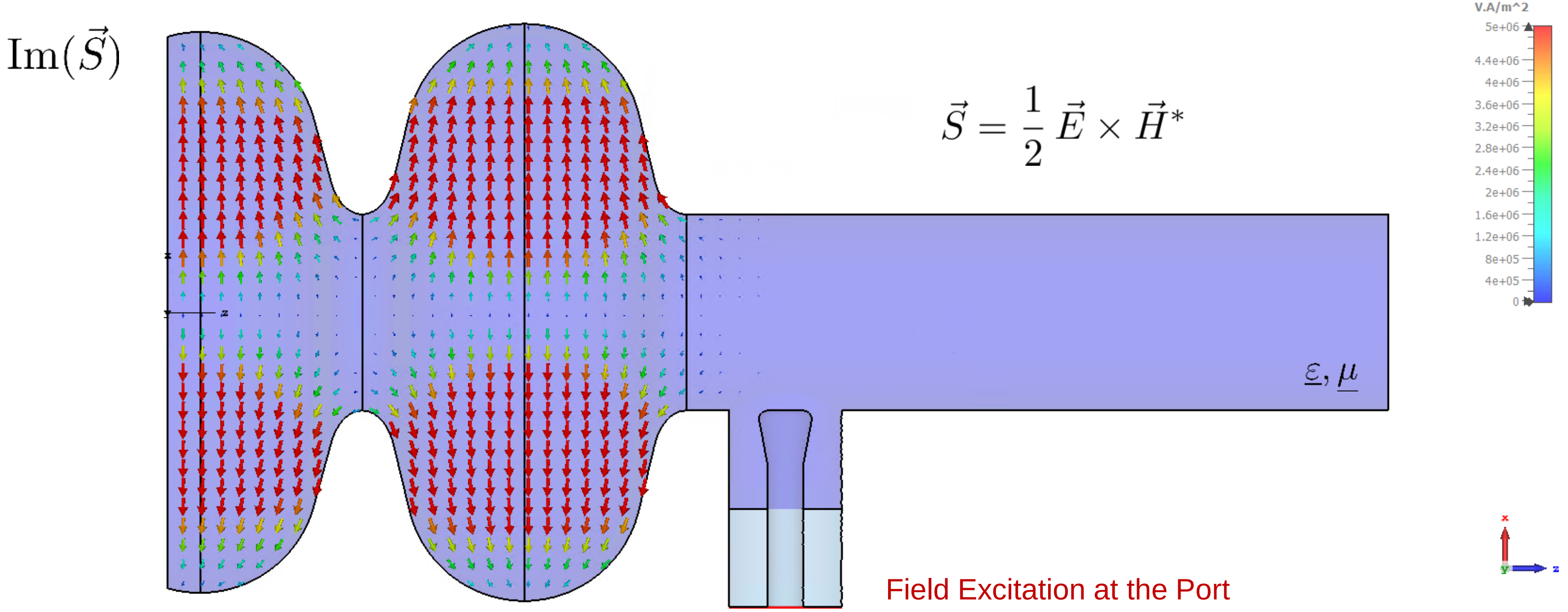
Numerical Results

Distribution of the Power Density



Numerical Results

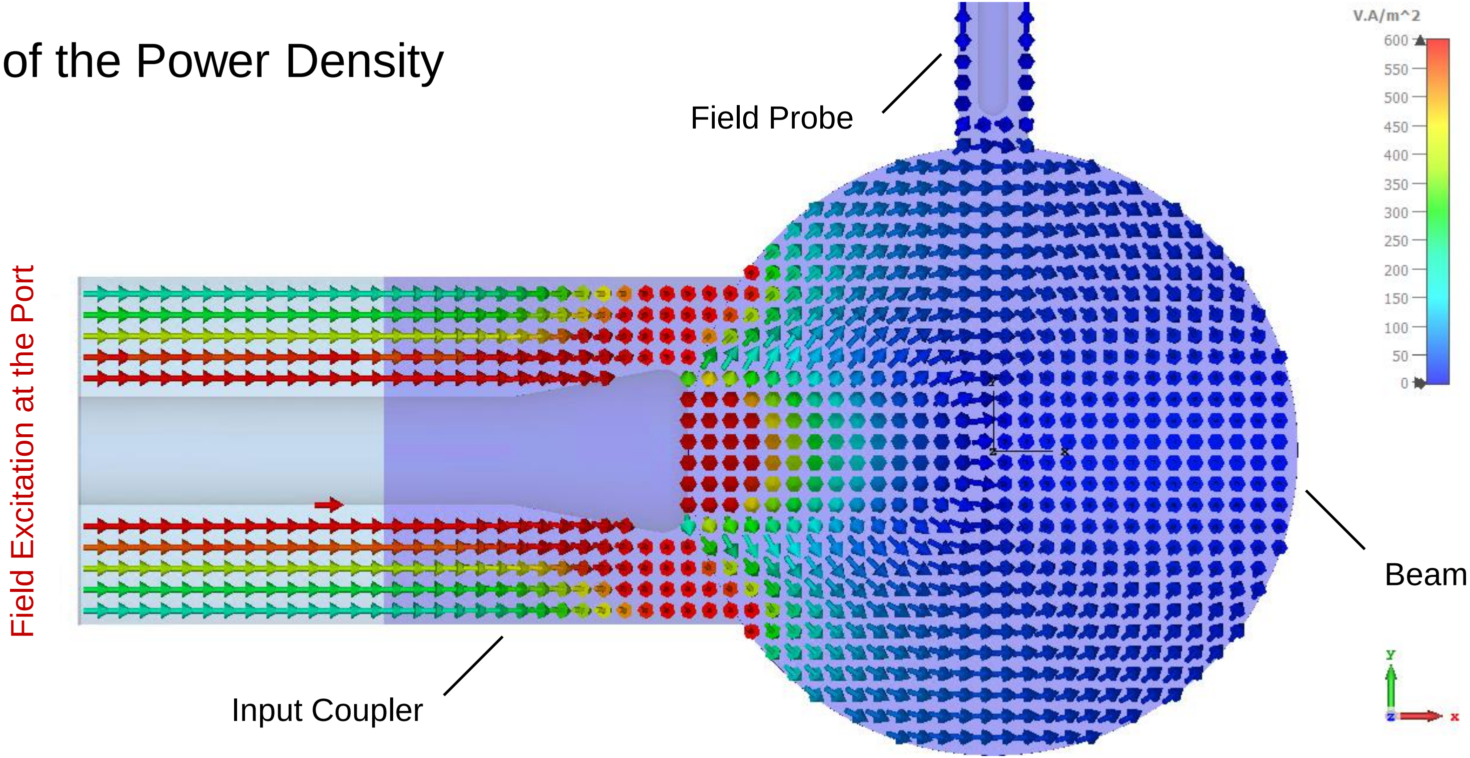
Distribution of the Power Density



Numerical Results

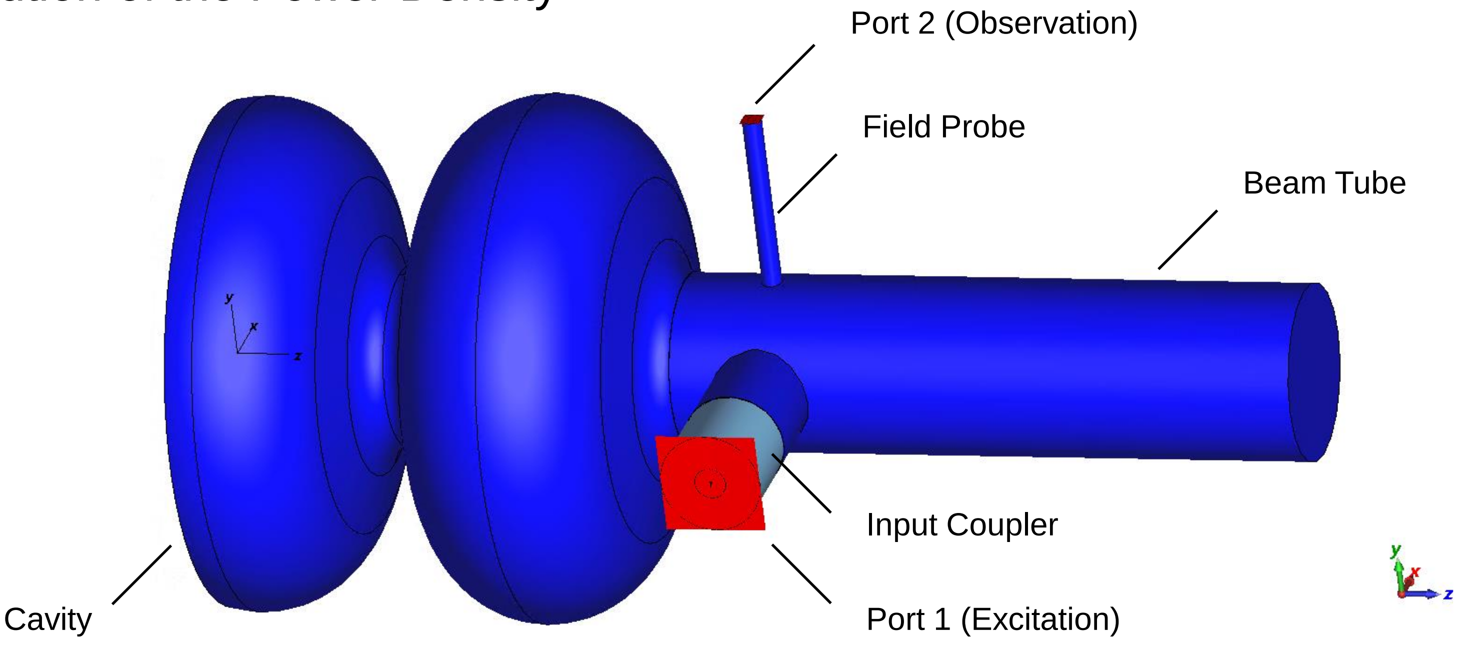
Distribution of the Power Density

$\mathrm{Re}(\vec{S})$



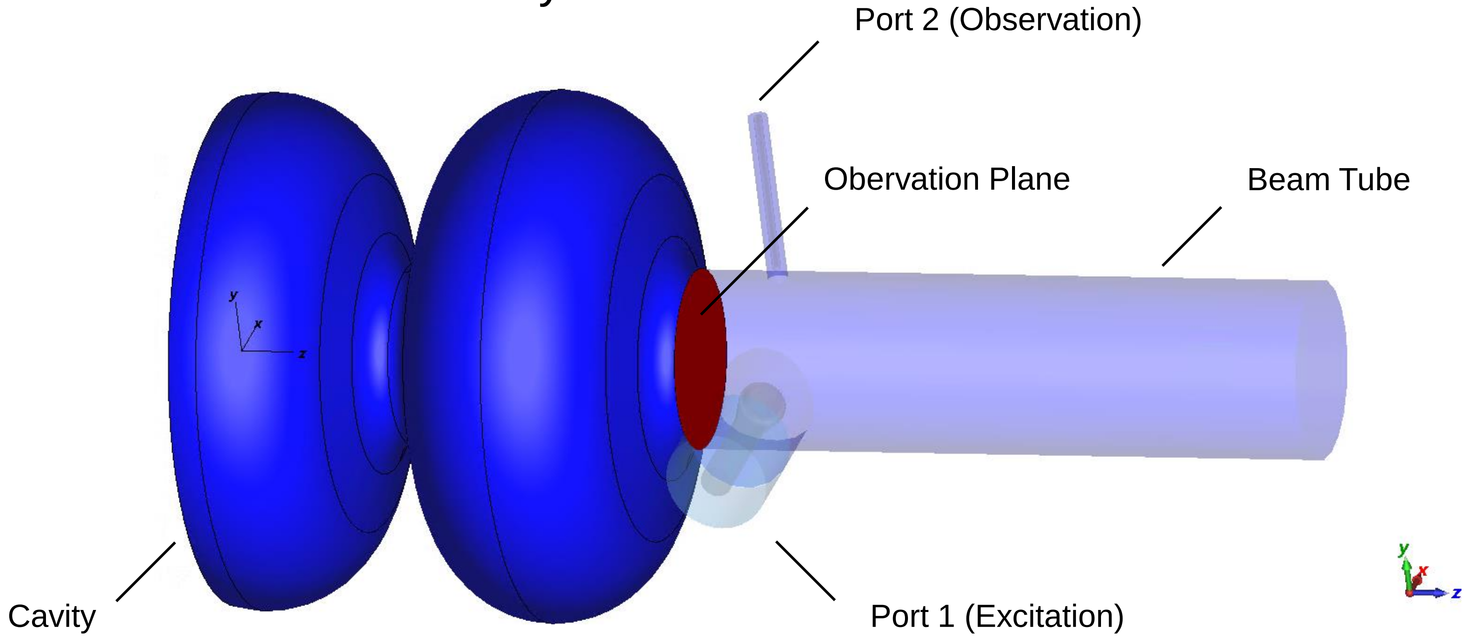
Numerical Modeling

Distribution of the Power Density



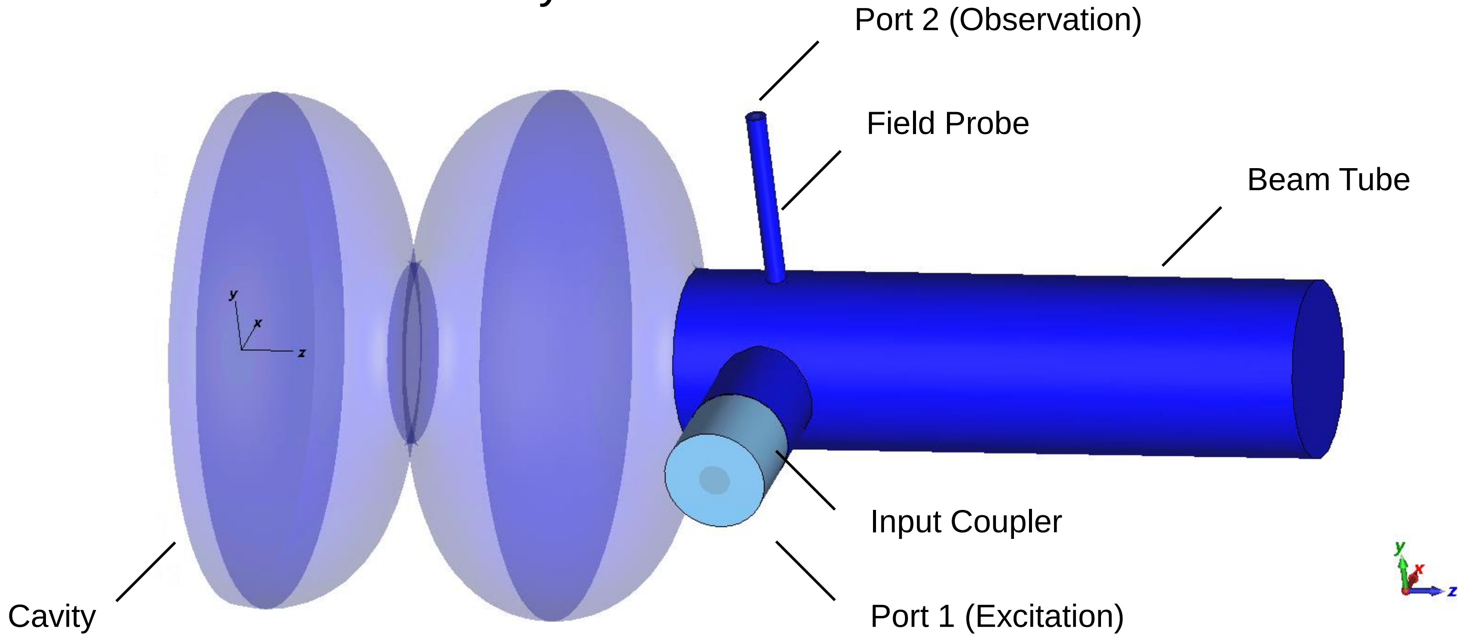
Numerical Modeling

Distribution of the Power Density



Numerical Modeling

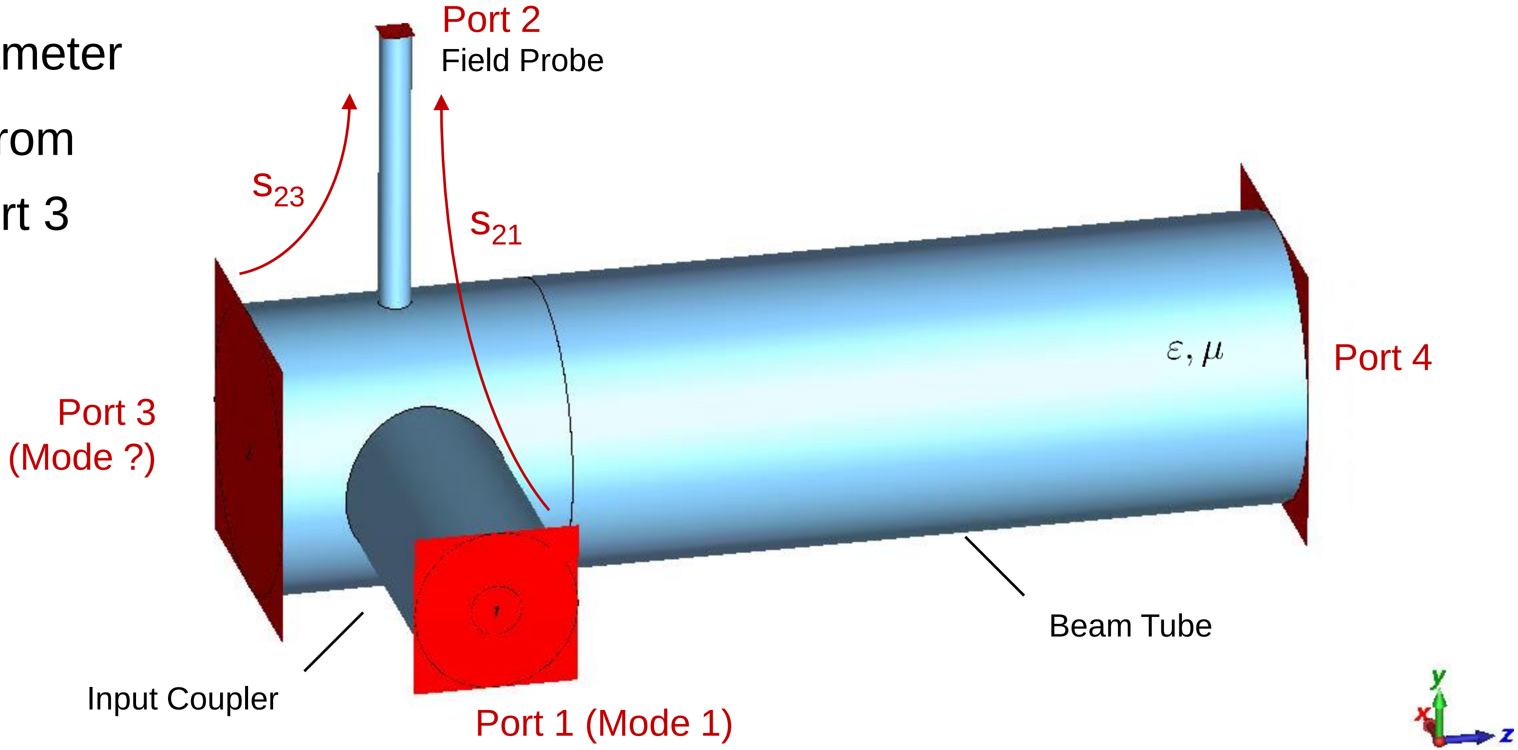
Distribution of the Power Density



Numerical Modeling

Scattering Parameter

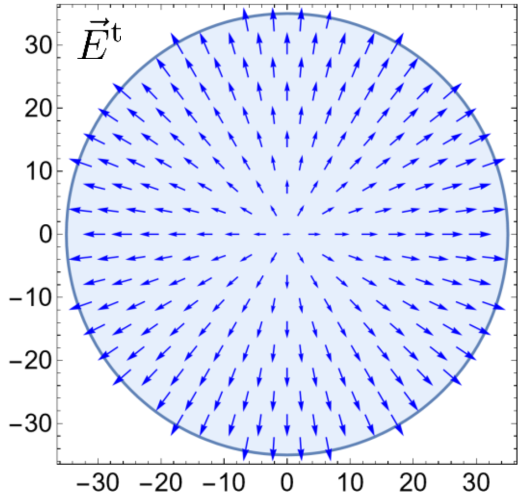
- Contribution from Port 1 and Port 3

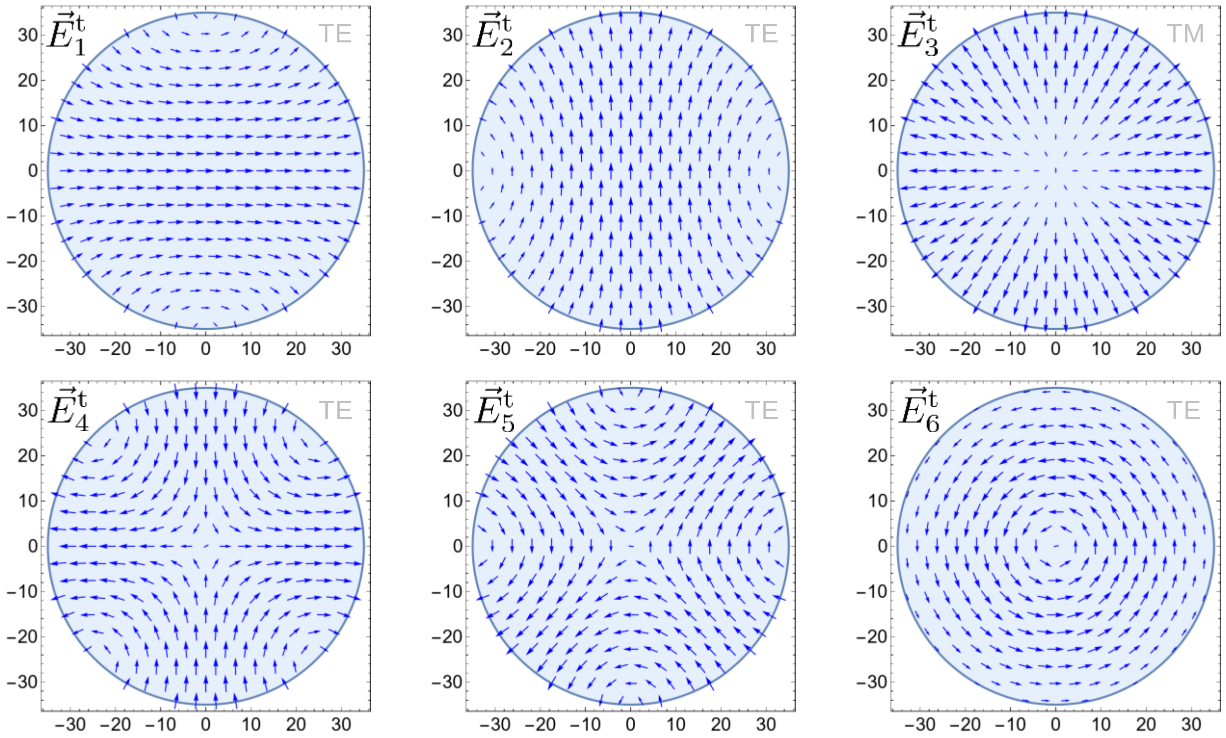


Numerical Results

Modal Expansion (Port 3)

$$\vec{E}^{\mathrm{t}} = \sum_{i=1}^{\infty} \underline{c}_i\, \vec{E}_i^{\mathrm{t}}$$

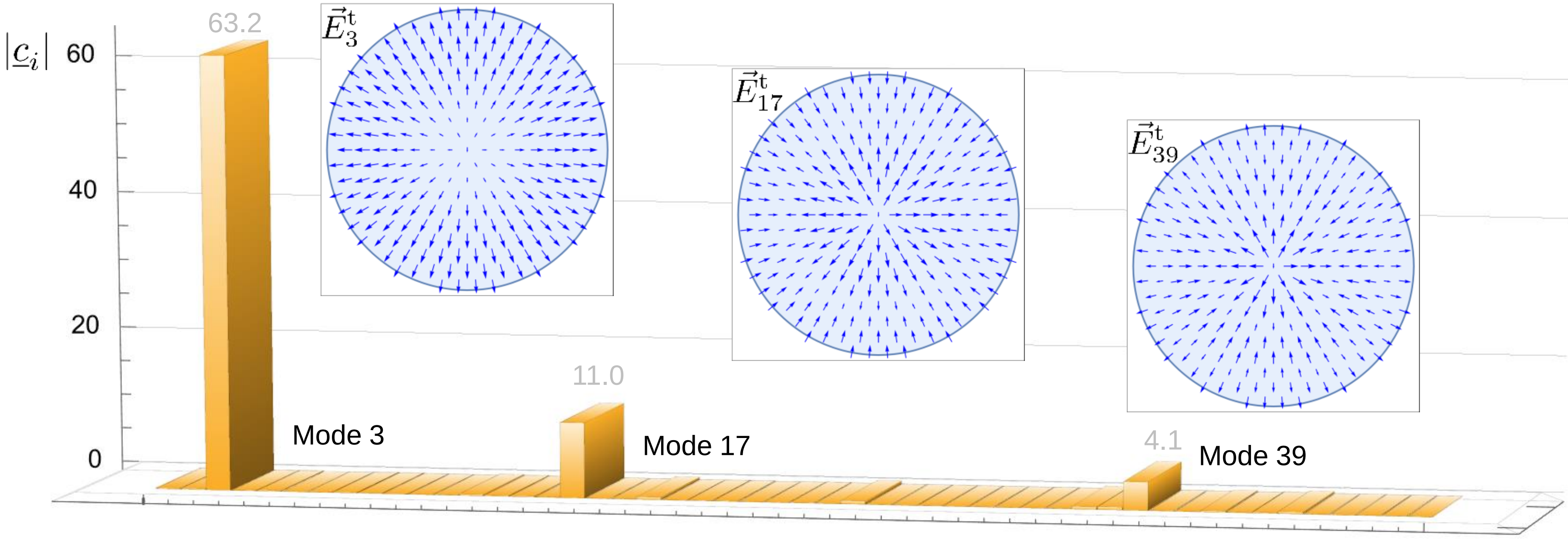




Numerical Results

Modal Expansion (Port 3)

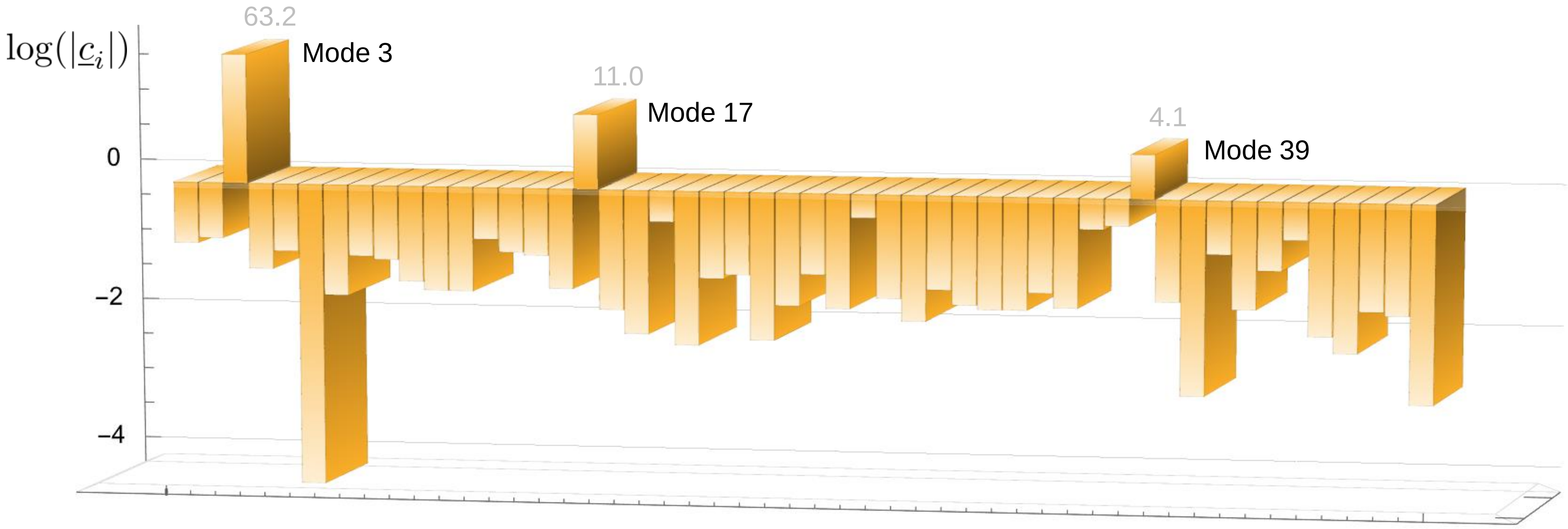
Absolute values of the modal coefficients



Numerical Results

Modal Expansion (Port 3)

Absolute values of the modal coefficients



Numerical Modeling

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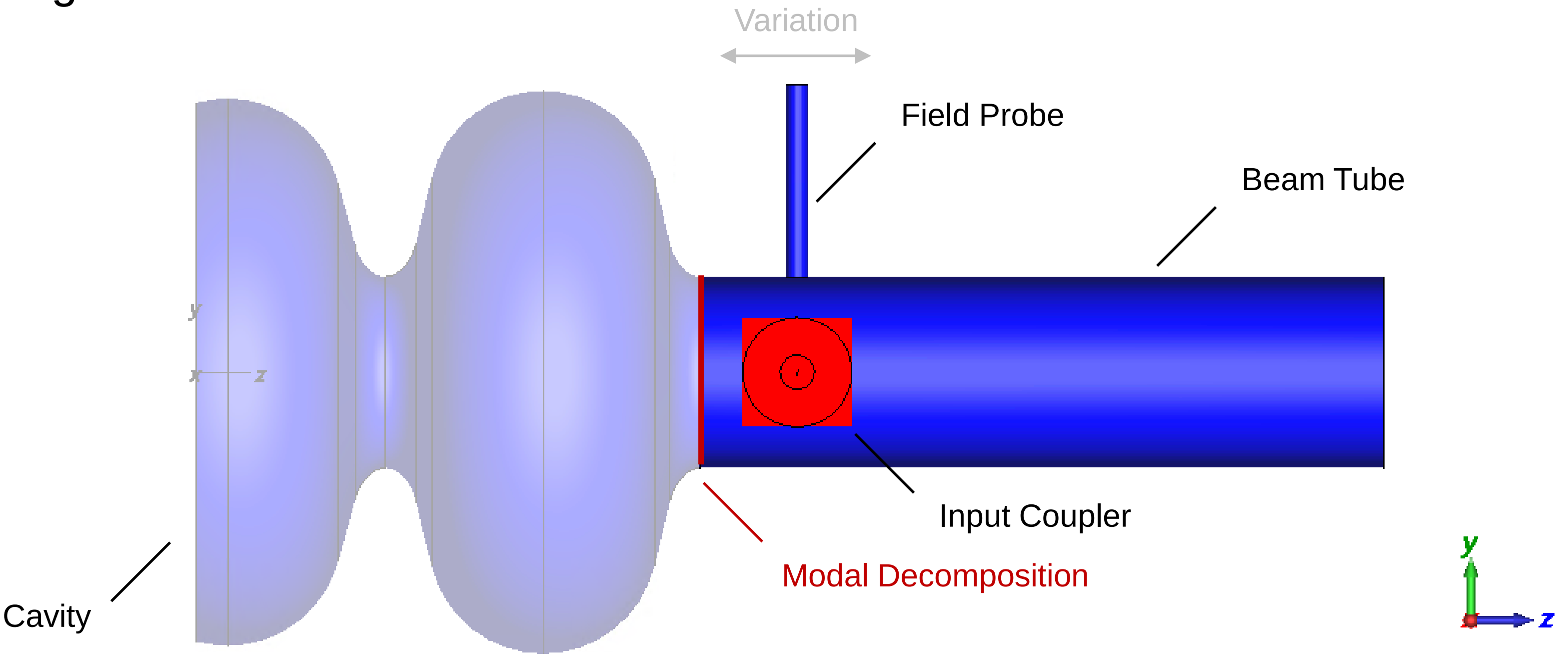
Scattering Parameter



Numerical Modeling

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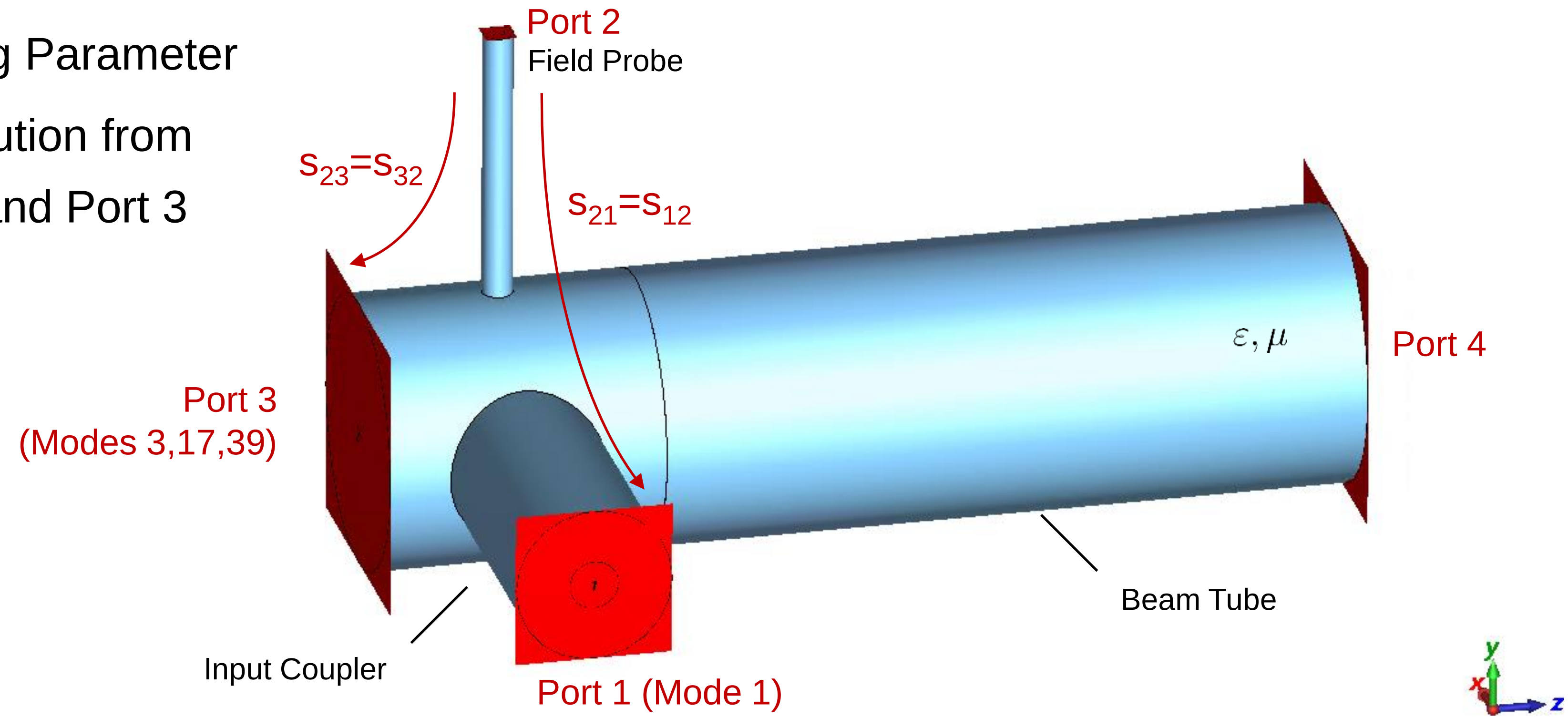
Scattering Parameter

- Contribution from Port 1 and Port 3



Numerical Results

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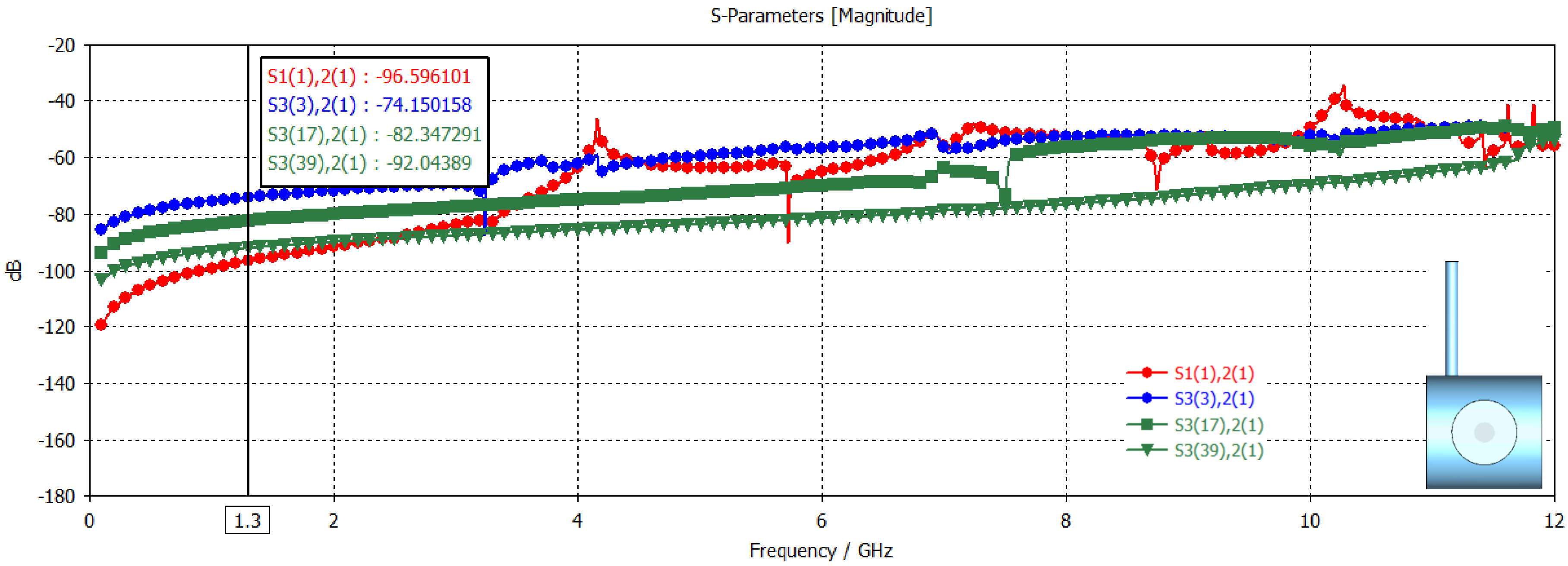
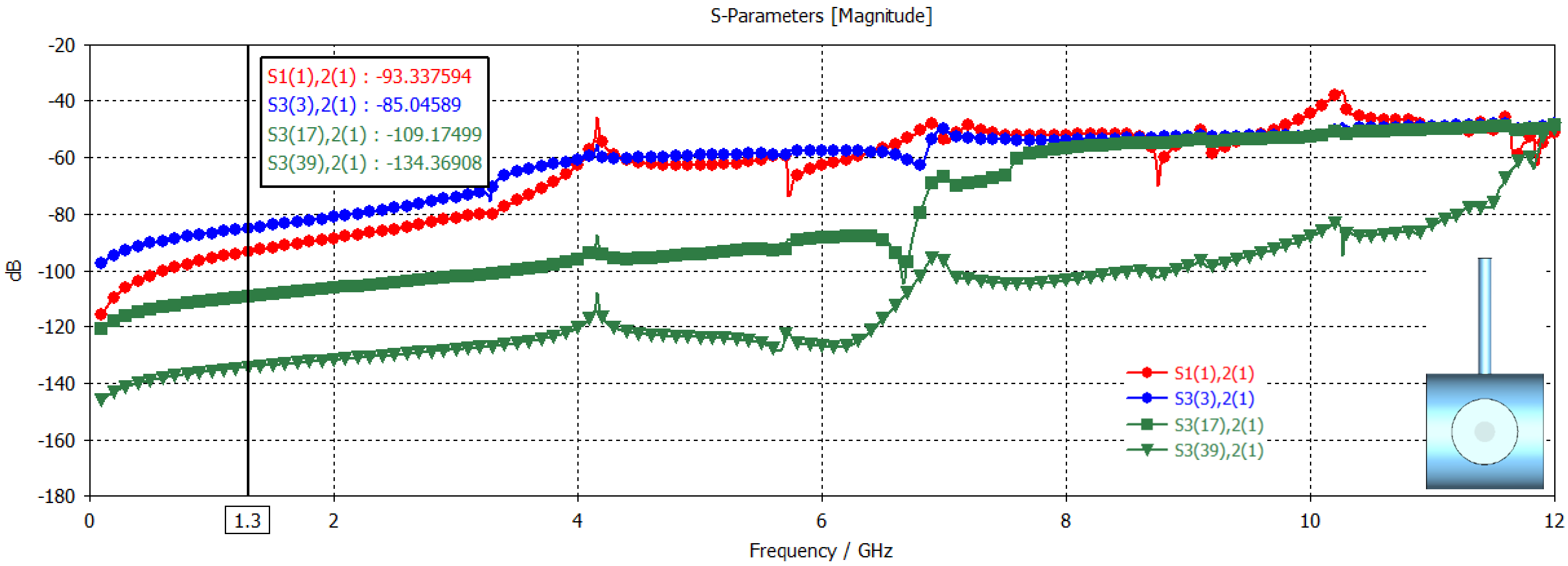
Scattering Parameter



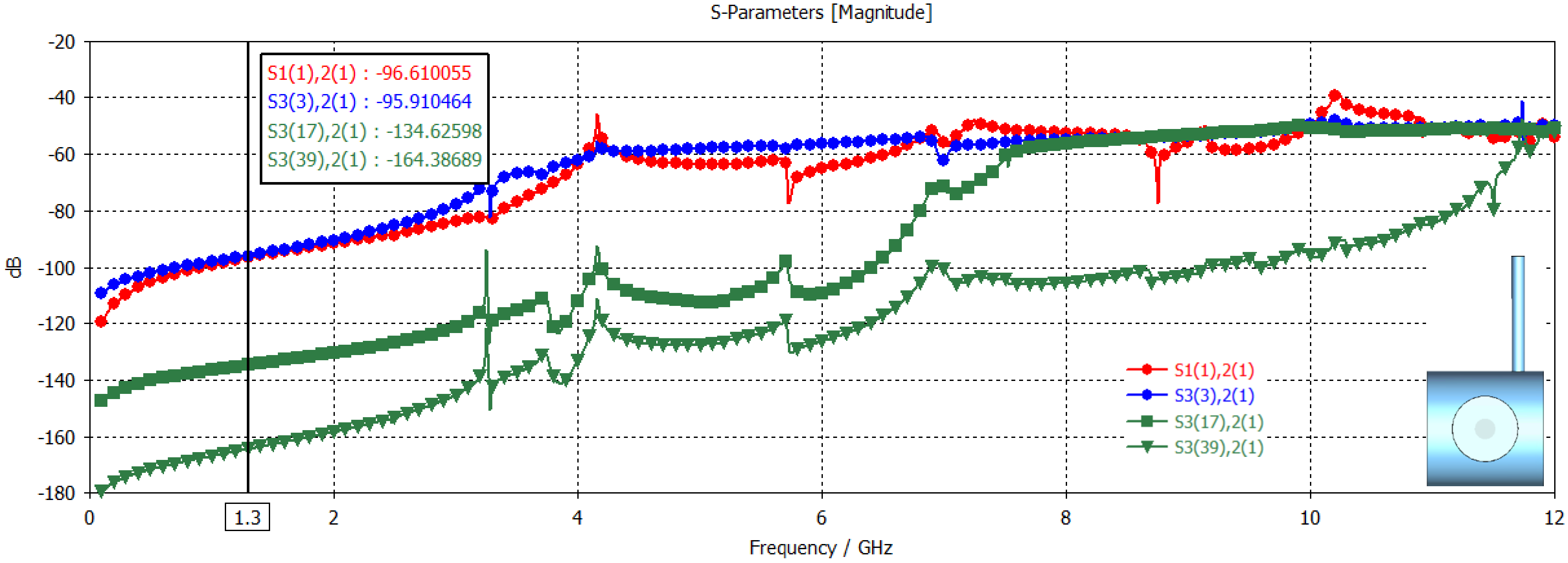
Numerical Results

Scattering Parameter



Numerical Results

Scattering Parameter



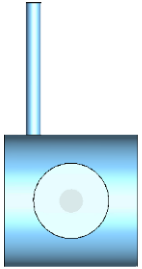
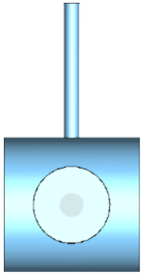
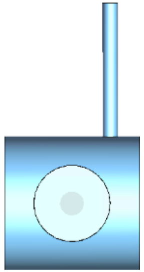
Numerical Results

Scattering Parameter

$f_0 = 1.3\,\mathrm{GHz}$

$a_1 = 20\,\log_{10}(\;1.0) = \;\;0.0\,\mathrm{dB}$

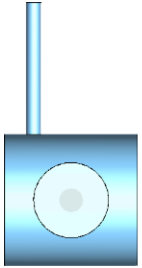
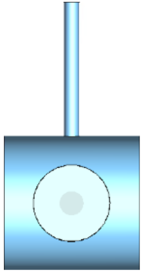
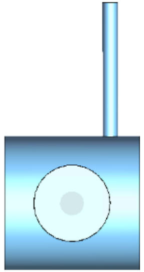
$a_3 = 20\,\log_{10}(63.2) = 36.0\,\mathrm{dB}$

		
$s_{12} = -96.6\,\mathrm{dB}$	$s_{12} = -93.3\,\mathrm{dB}$	$s_{12} = -96.6\,\mathrm{dB}$
$s_{32} = -74.2\,\mathrm{dB}$	$s_{32} = -85.0\,\mathrm{dB}$	$s_{32} = -95.9\,\mathrm{dB}$
$b_{12} = -96.6\,\mathrm{dB}$	$b_{12} = -93.3\,\mathrm{dB}$	$b_{12} = -96.6\,\mathrm{dB}$
$b_{32} = -38.2\,\mathrm{dB}$	$b_{32} = -49.0\,\mathrm{dB}$	$s_{32} = -59.9\,\mathrm{dB}$
$\Delta = 58.4\,\mathrm{dB}$	$\Delta = 44.3\,\mathrm{dB}$	$\Delta = 36.7\,\mathrm{dB}$

Numerical Results

Scattering Parameter

$f_0 = 1.3\,\mathrm{GHz}$

$a_1 = 20\,\log_{10}(\,1.0) = 0.0\,\mathrm{dB}$	$b_{12} = -96.6\,\mathrm{dB}$	$b_{12} = -93.3\,\mathrm{dB}$	$b_{12} = -96.6\,\mathrm{dB}$
$a_3 = 20\,\log_{10}(63.2) = 36.0\,\mathrm{dB}$	$b_{32} = -38.2\,\mathrm{dB}$	$b_{32} = -49.0\,\mathrm{dB}$	$s_{32} = -59.9\,\mathrm{dB}$
	$\Delta = 58.4\,\mathrm{dB}$	$\Delta = 44.3\,\mathrm{dB}$	$\Delta = 36.7\,\mathrm{dB}$
$a_3 = 20\,\log_{10}(6.32) = 16.0\,\mathrm{dB}$	$\Delta = 38.4\,\mathrm{dB}$	$\Delta = 24.3\,\mathrm{dB}$	$\Delta = 16.7\,\mathrm{dB}$
$a_3 = 20\,\log_{10}(0.63) = -4.0\,\mathrm{dB}$	$\Delta = 18.4\,\mathrm{dB}$	$\Delta = 4.3\,\mathrm{dB}$	$\Delta = -3.3\,\mathrm{dB}$

Summary

Work and Results

- Precise numerical modeling of the SRF gun including the input power coupler and the pickup probe
- Calculation in the frequency domain enables simultaneous excitation and extraction of fields at the ports
- S-parameter calculations allow to distinguish between cavity and excitation fields
- While the separation is sufficient for the matched operation it will be difficult to separate the contributions in the unmatched case
- This observation is even worse during transients when high-frequency components are present in the excitation signal