Trapped mode analysis for the PETRA-4 IVUs

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Problem Description

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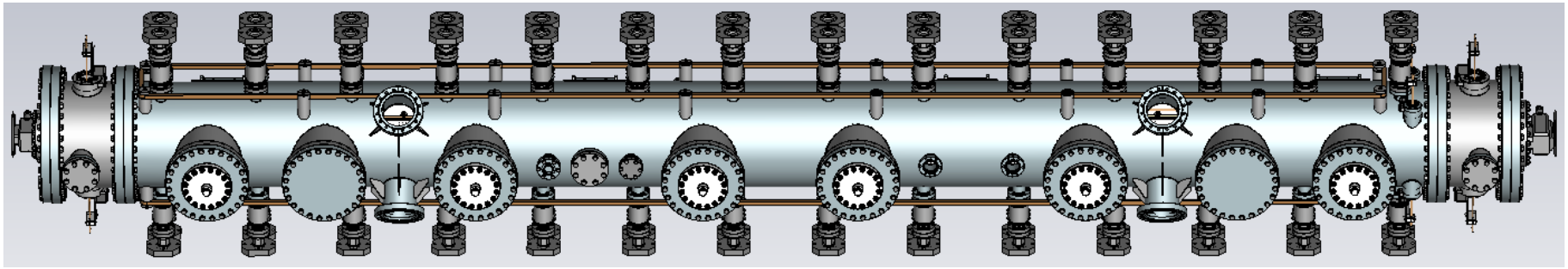
- Task
  - Identification of modes, resonance frequencies and quality factors
- Creation of an accurate and efficient model
- Measurement of S-parameters as reference
- Work in progress



Content

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- Problem Description
- Geometry
- Eigenmode Analysis
- Q-Factors
- Comparison with Measurement
- Periodic Model
- Conclusion

Geometry

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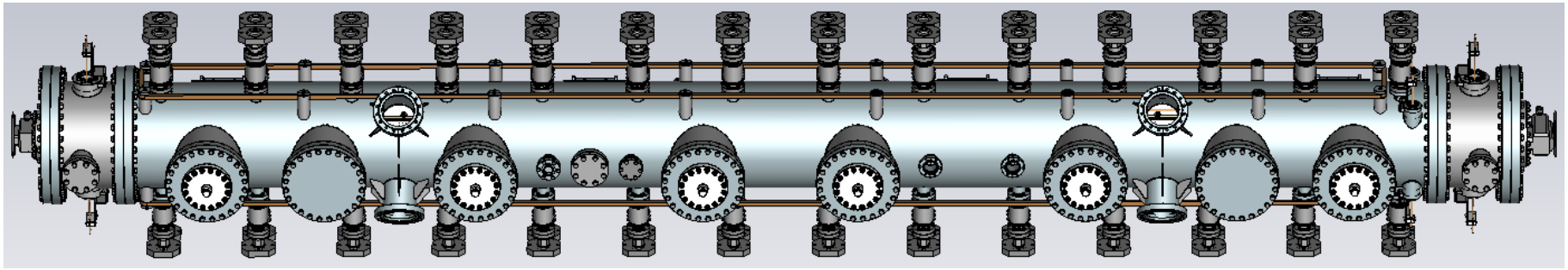
Orginal CAD model



Geometry

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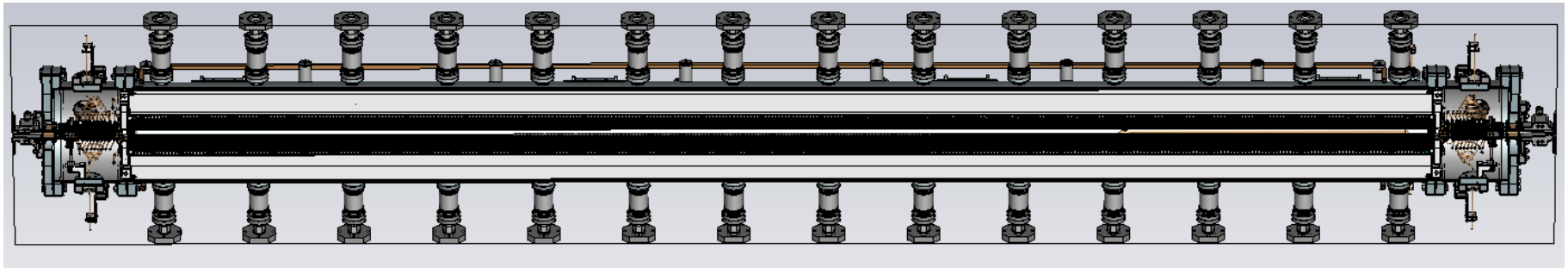
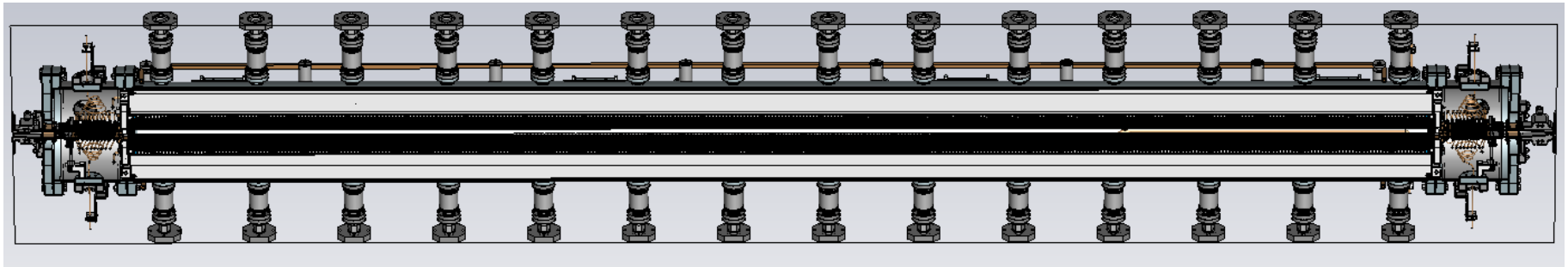
Orginal CAD model



Geometry

Orginal CAD model



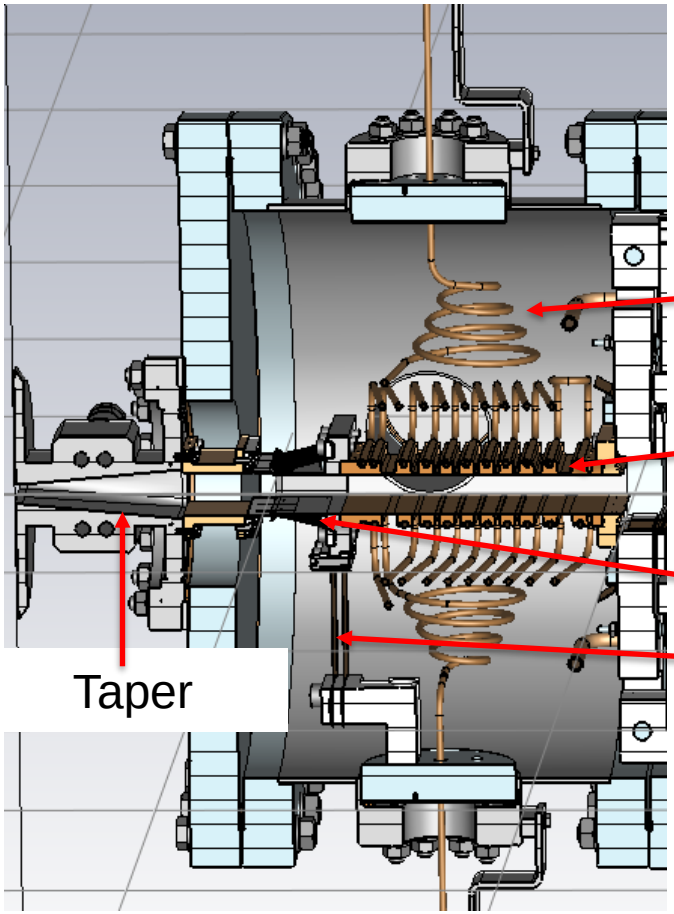
Entry Body Exit

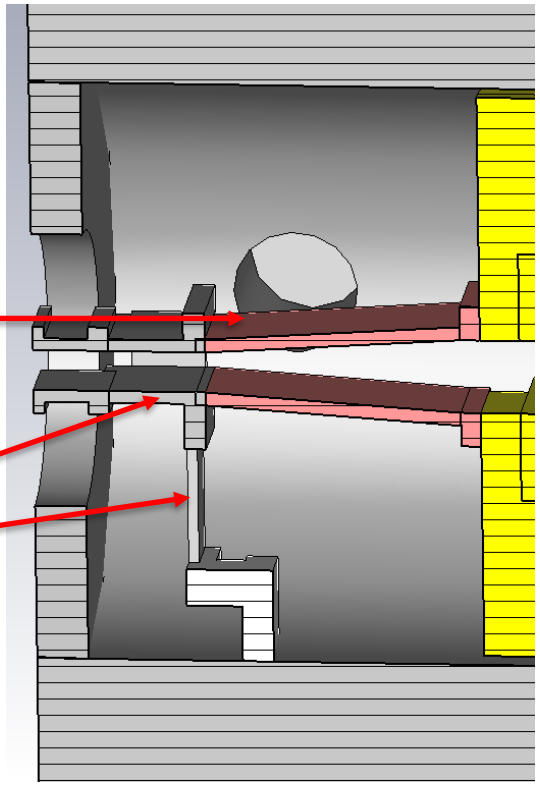
Grey: stainless steel
Yellow: aluminum
Red: copper

Geometry

Entry and exit sections

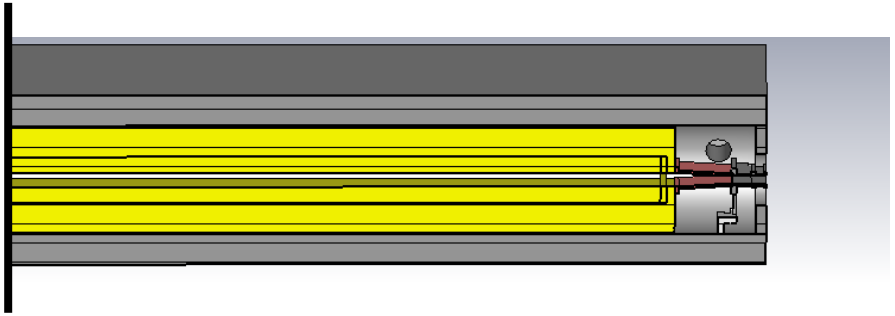
Grey: stainless steel
Yellow: aluminum
Red: copper

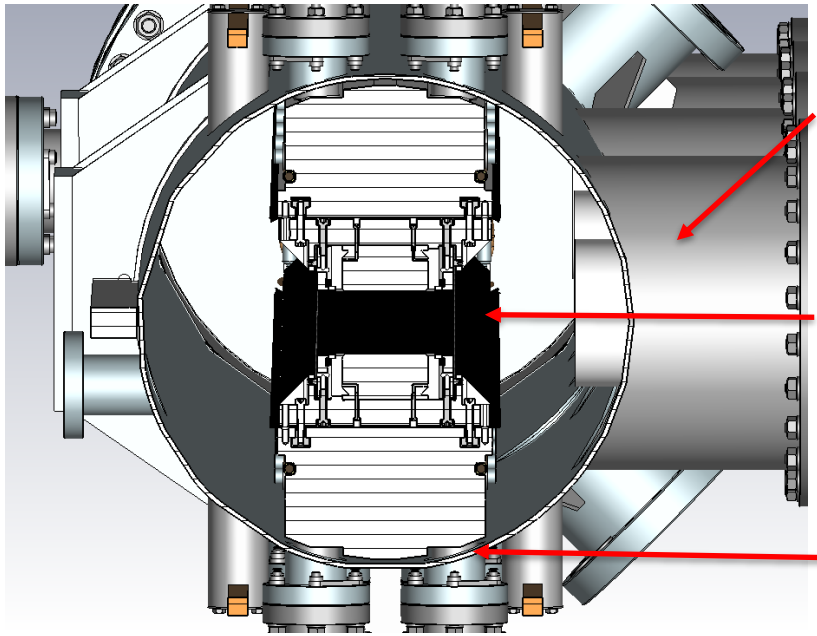




Geometry

Body

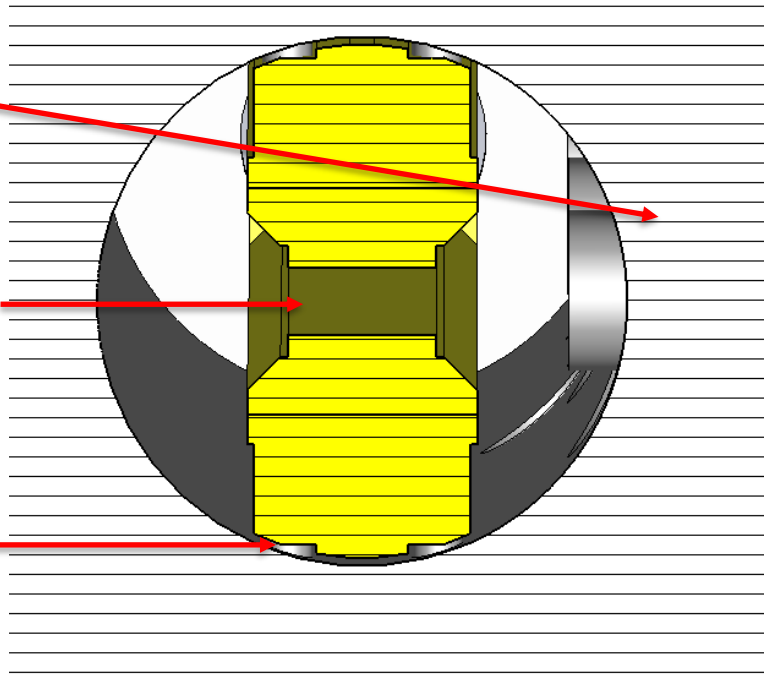




Vacuum ports

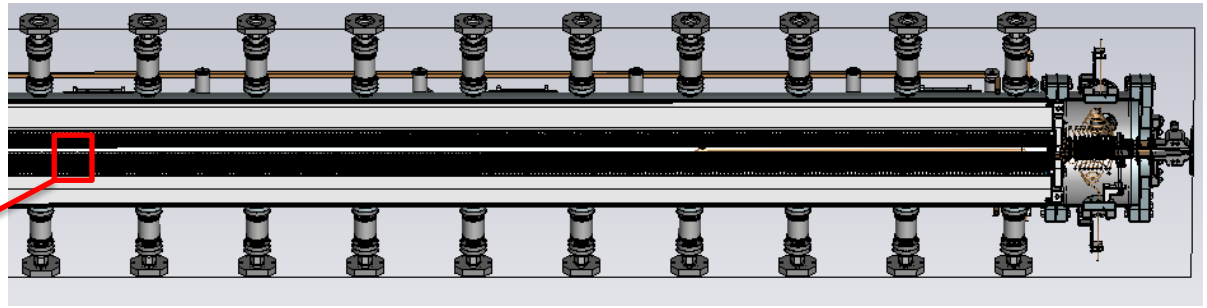
Magnet structure

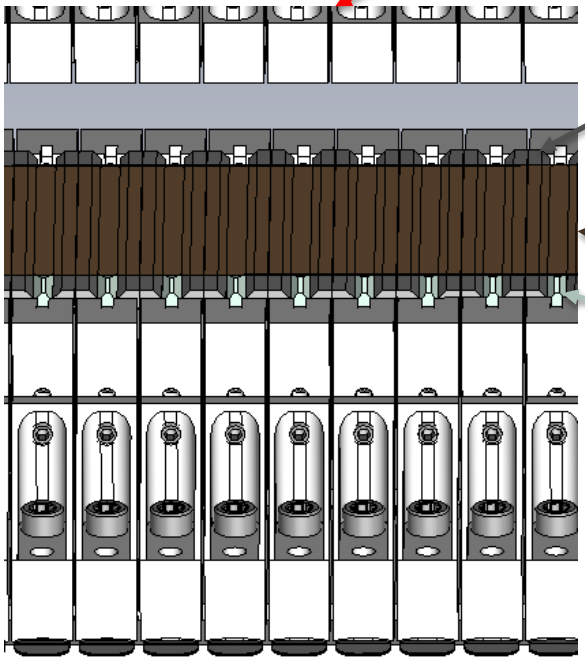
Pillars



Geometry

Perdiodic magnet structure

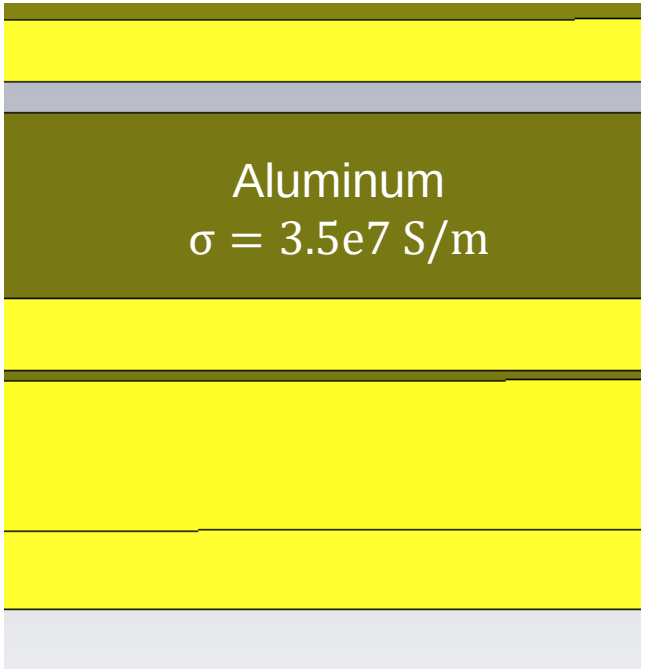




NdFeB
$\sigma = 0.7e6\ S/m$
$\mu_r = 1$

Copper / nickel

CoFeV
$\sigma = 2e6\ S/m$
$\mu_r = 18000$



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Eigenmode Analysis

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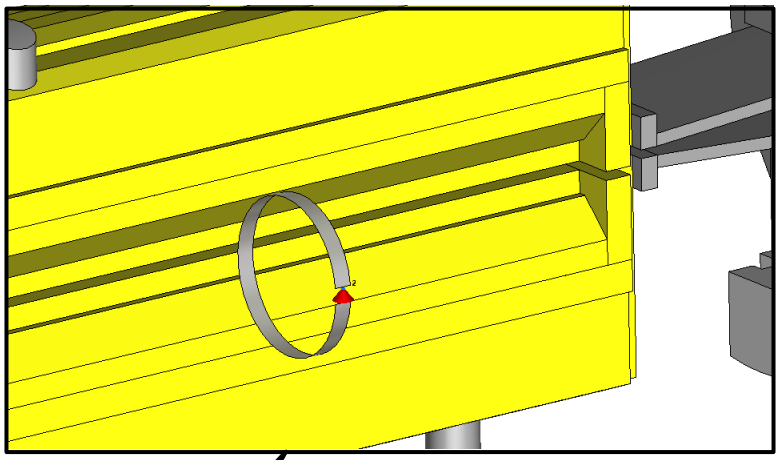
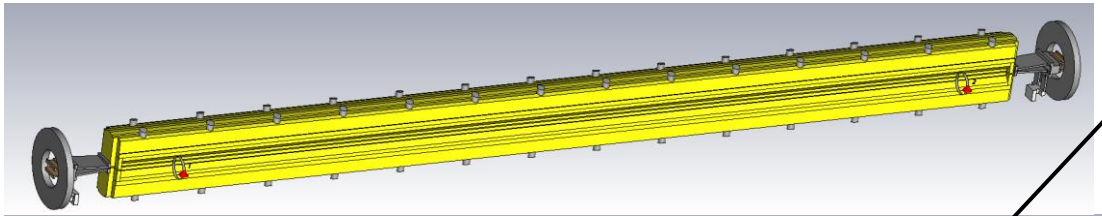
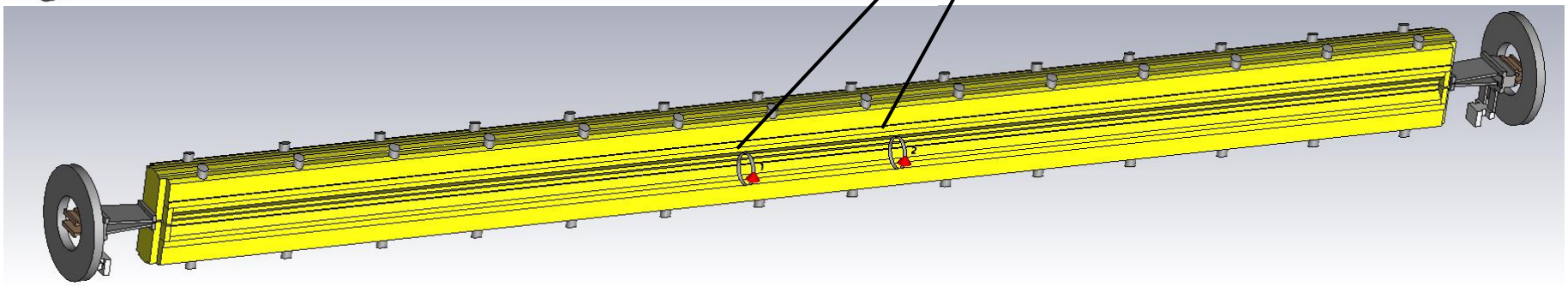
Simulation procedure

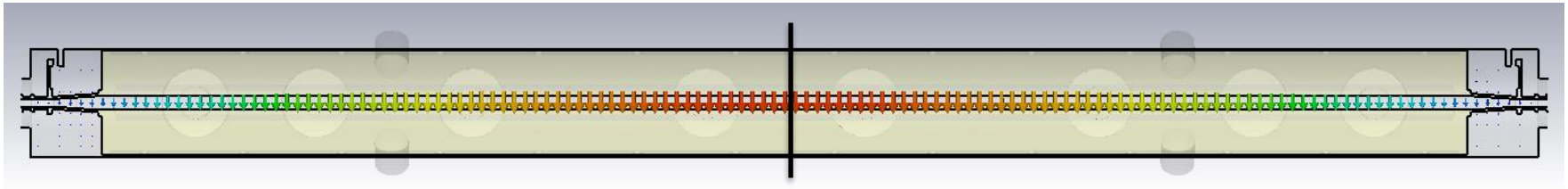
- Eigenmode solver in 3D
  - Efficient
- S-parameter simulation
  - Confirm eigenmode solution





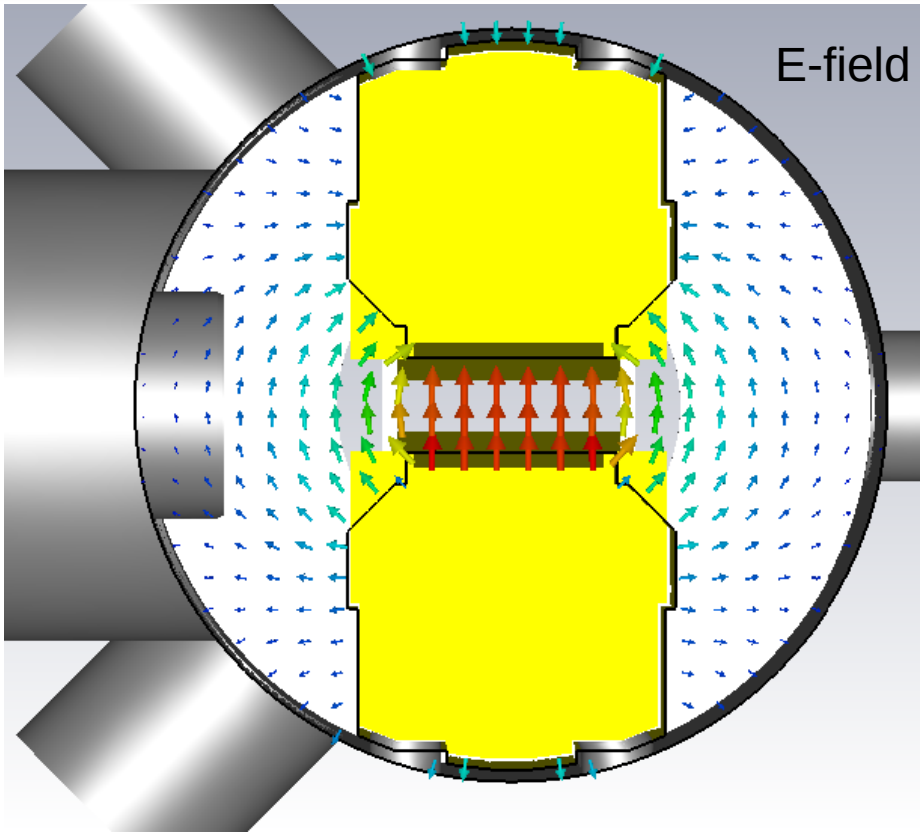


Eigenmode Analysis



Field distribution

- Ground mode at 234MHz, gap=40mm
- Strong field in the „plate capacitor“
- Significant field concentration between the pillars



Eigenmode Analysis

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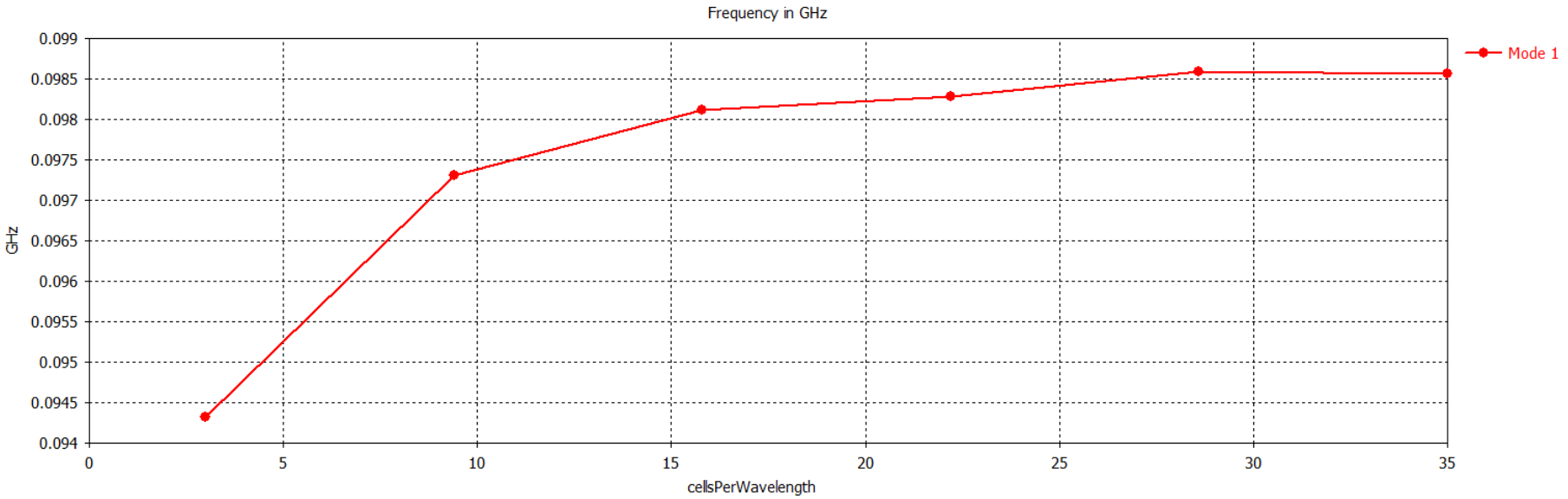
Mesh convergence

- Eigenmode solver
- Ground mode, **gap=5mm**
- #tets=20k…2M
- ≈0.5% error at 15 cells per wavelength



Eigenmode Analysis

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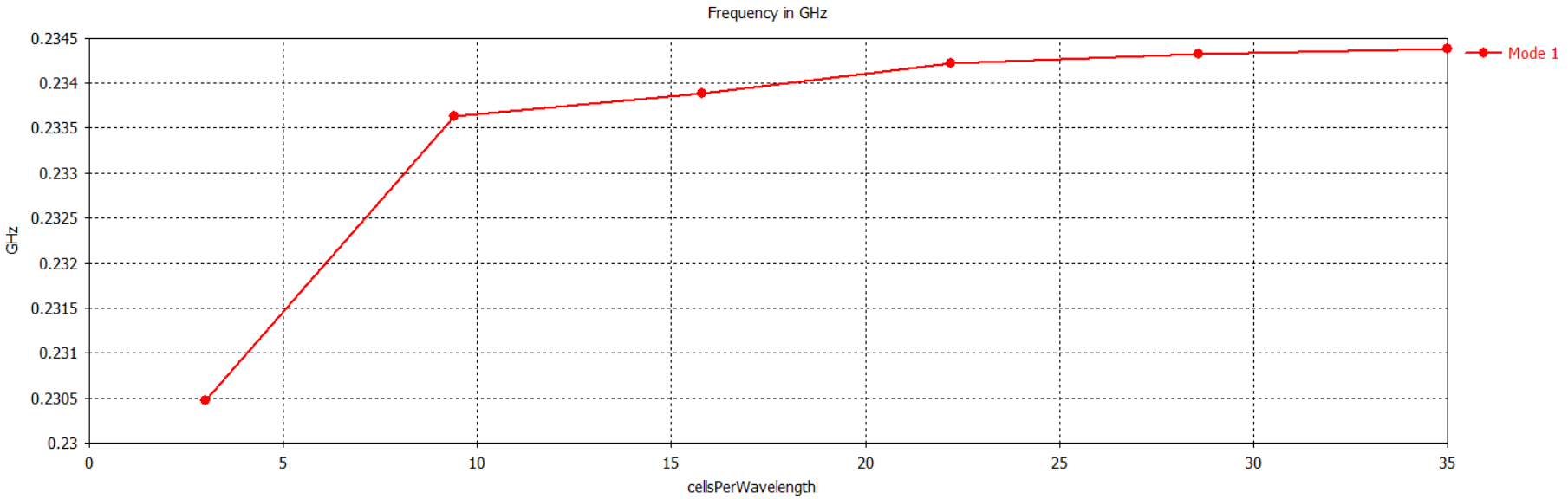
Mesh convergence

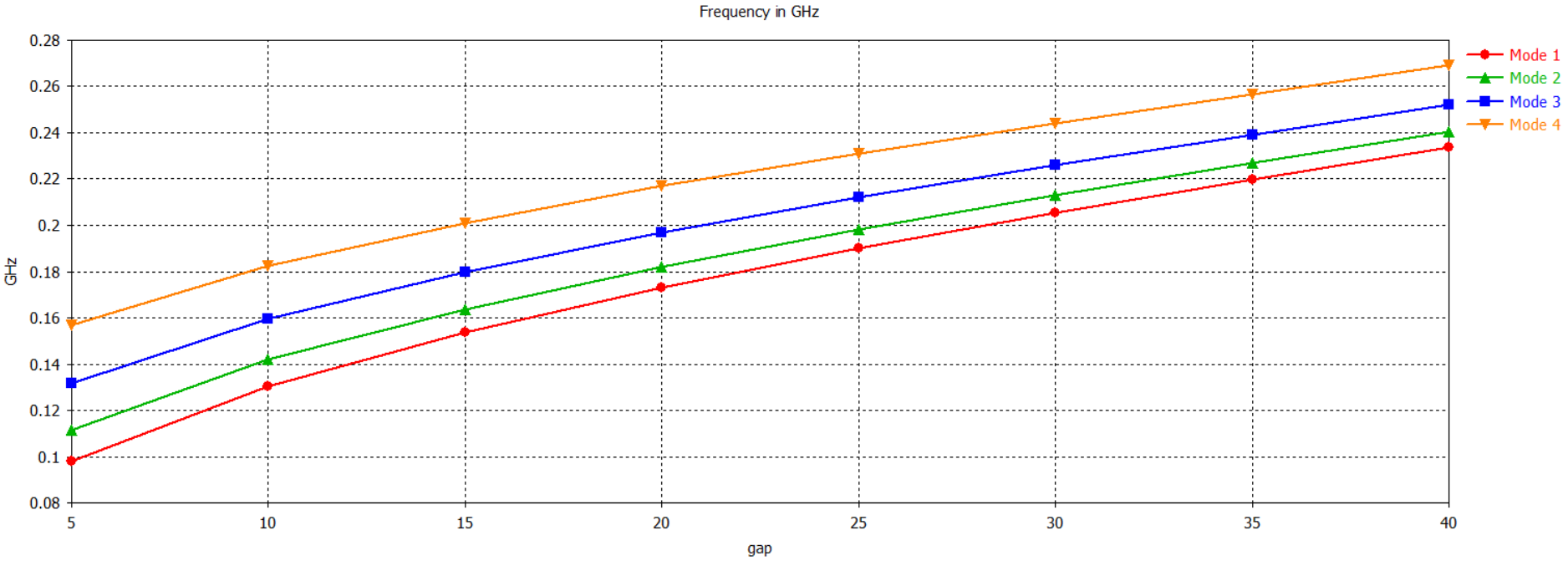
- Eigenmode solver
- Ground mode, **gap=40mm**
- #tets=20k…2M
- ≈0.2% error at 15 cells per wavelength



Eigenmode Analysis

Gap sweep

- Resonance frequencies rising monotonously



Eigenmode Analysis

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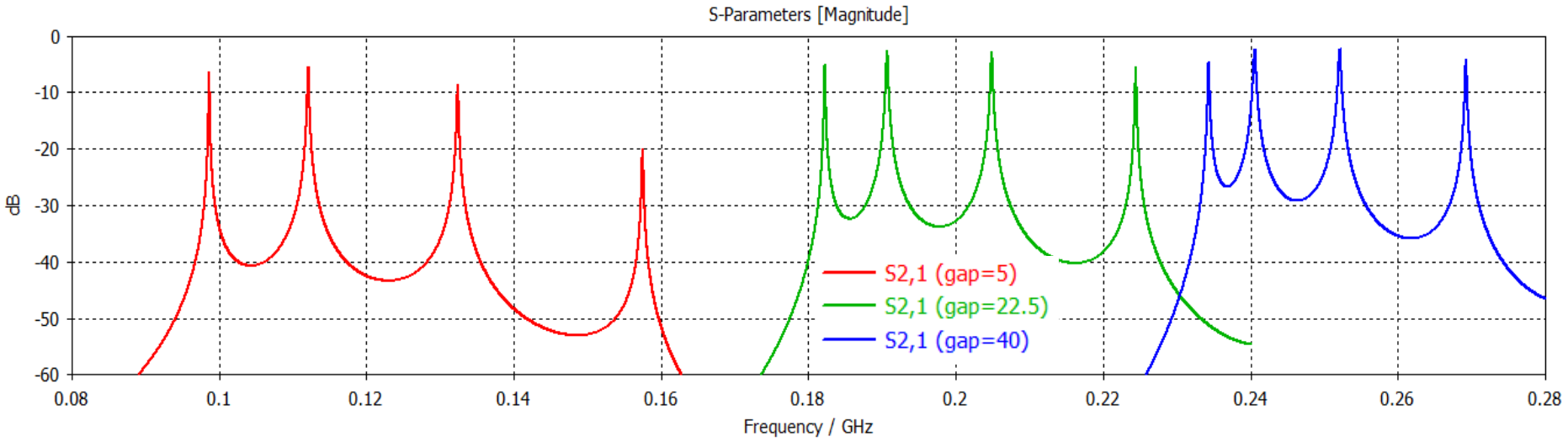
S-parameter simulation

- Perfect agreement with eigenvalue solver (error < 1%)

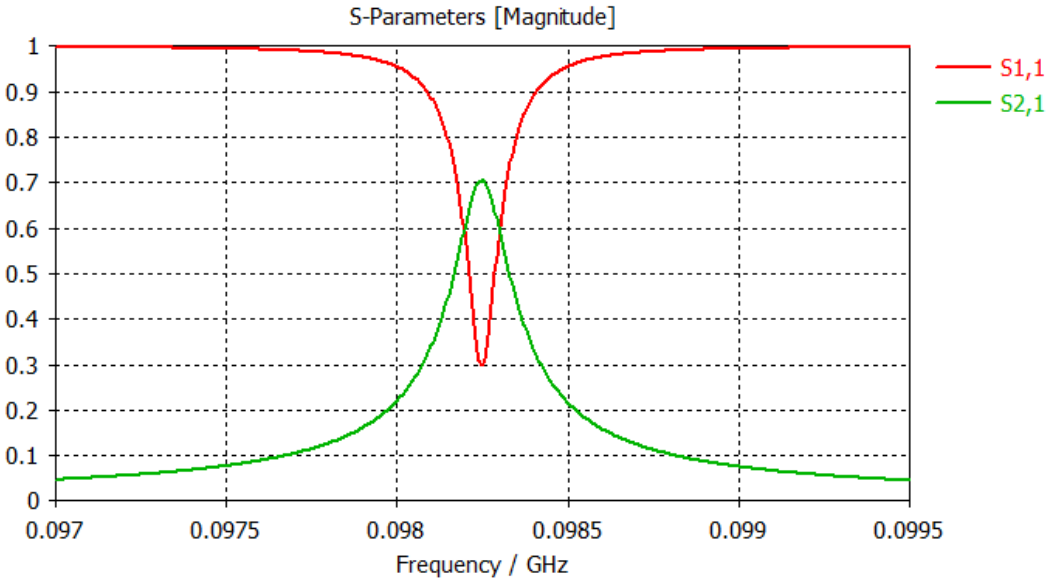
Resonance frequencies of ground mode

Gap	5mm	40mm
Eigen.	98.2MHz	233.9MHz
Driven	98.6MHz	234.3MHz



Q-Factors

- Gap=5mm
- Ground mode
- Eigenmode solution
  - Power-loss method
  - Q_0=2300
- Frequency driven
  - Lossy metals (surface impedance)
  - Q_L=600
  - Q_0=2400
    - Same for different coupler / antennas
- Good agreement



Calculation of Q_0 in the overcoupled case

$$\beta_1 = \frac{1+|S_{11}|}{1-|S_{11}|},\ \beta_2 = \frac{|S_{21}|^2}{1-|S_{11}|^2-|S_{21}|^2}$$

$$Q_0 = Q_L(1+\beta_1+\beta_2)$$

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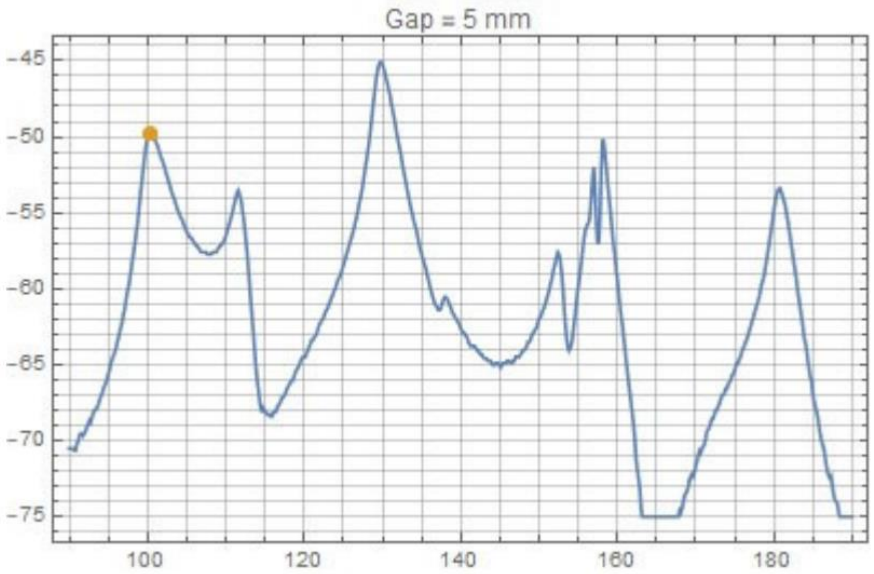
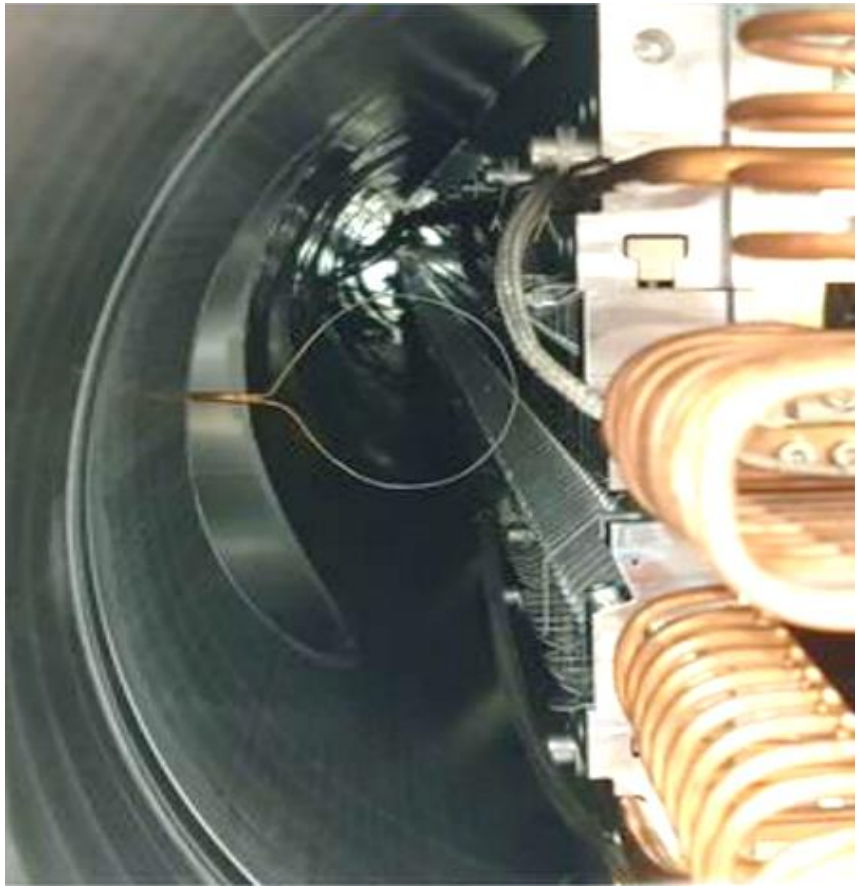
Comparison with Measurement

Setup

- Measurement from M. Ebert, P. Fuchs, P. Vagin, A. Schoeps (16.12.18)

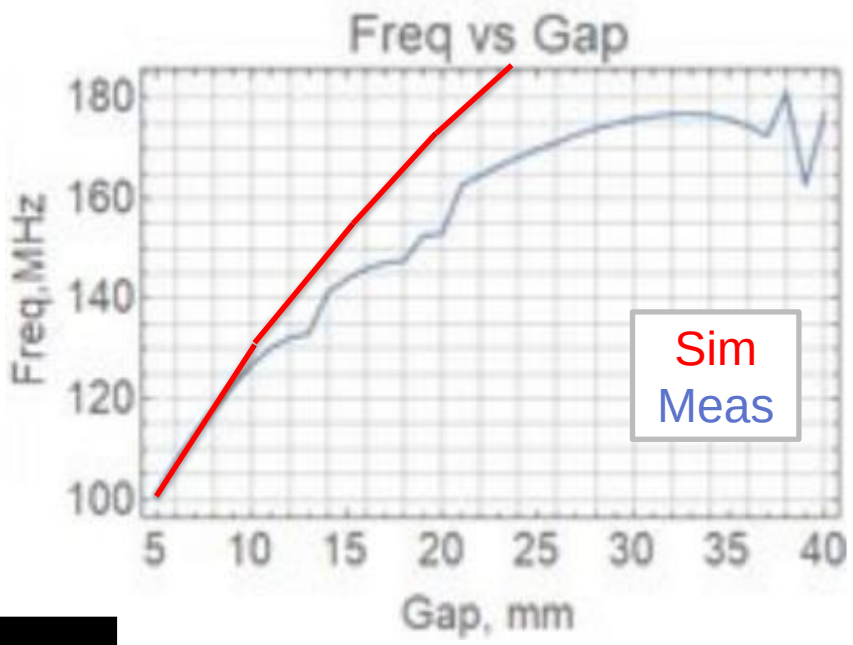




Comparison with Measurement

Resonance frequency

- Ground mode
- Good agreement at small gaps
- Larger error at large gaps



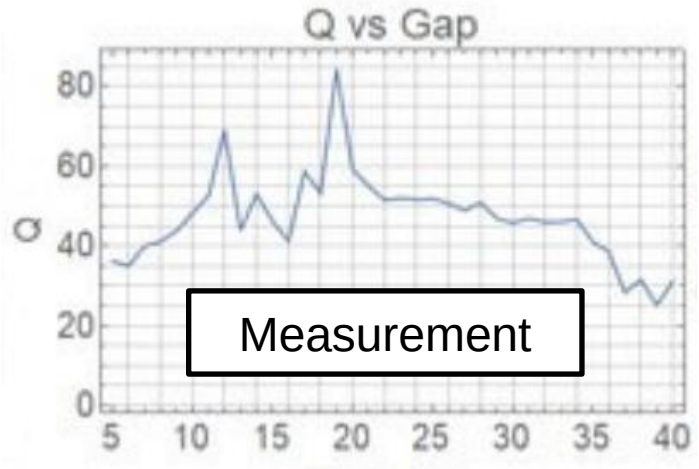
Resonance frequencies of ground mode in MHz

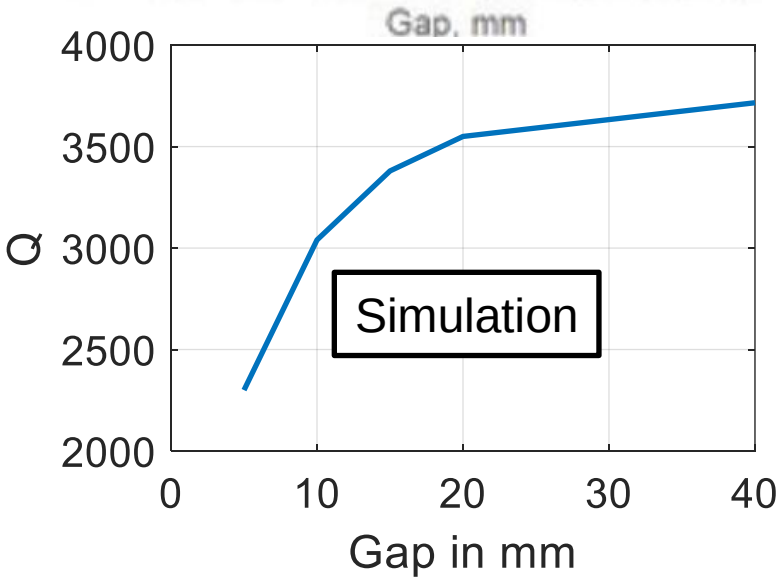
Gap	5mm	25mm	40mm
Measurement	100	170	177
Simulation	99	190	234
Relative error	1%	12%	32%

Comparison with Measurement

Q-factor comparison

- Large discrepancy
- Measurement setup?
  - Assumption: measured Q is Q_L
  - In simulation Q_L > 600
- Material parameters?
  - NdFeB magnets + CoFeV
  - Mostly covered by the copper foil
- Ferrite dampers installed?





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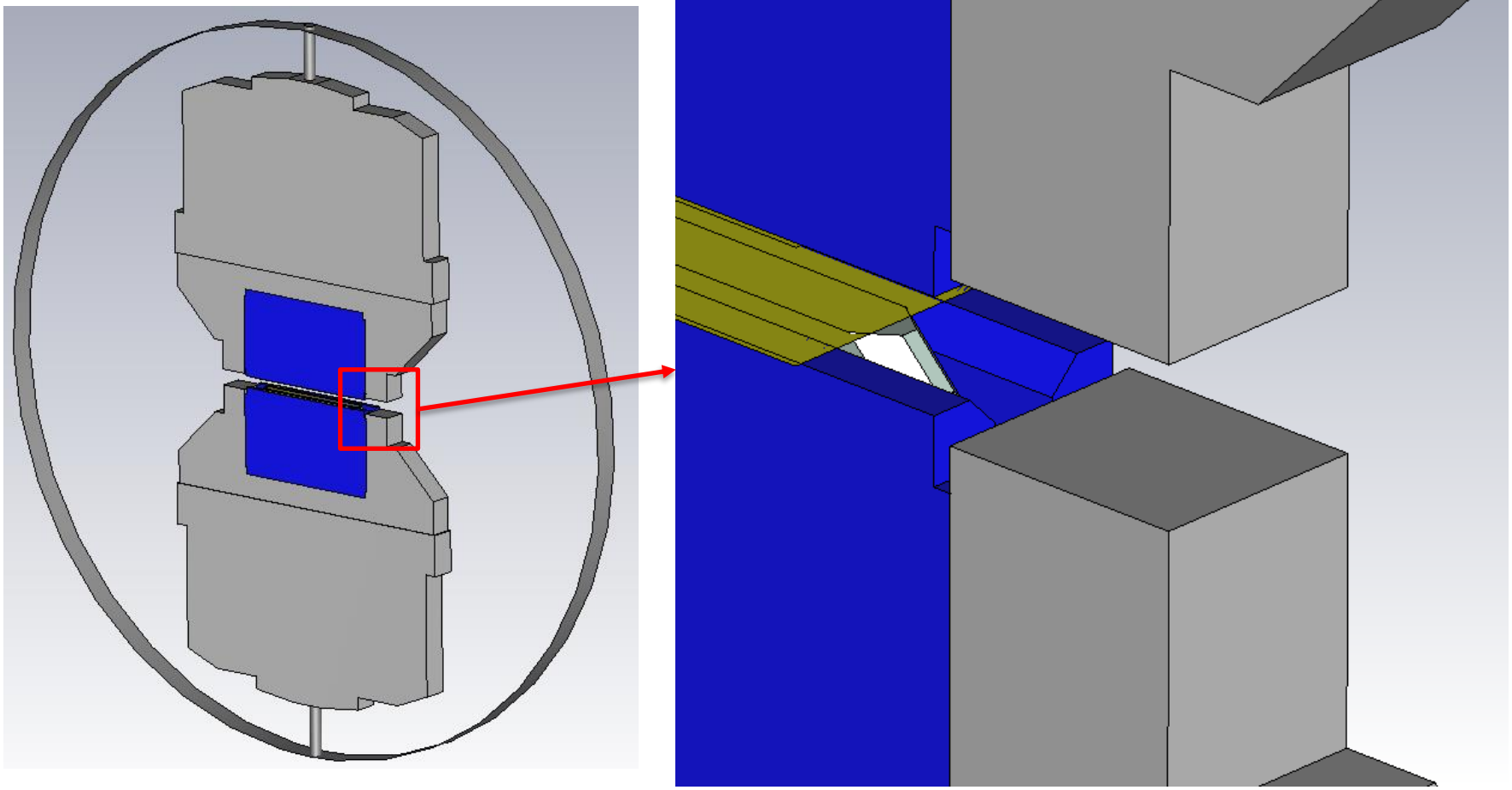
Periodic Model

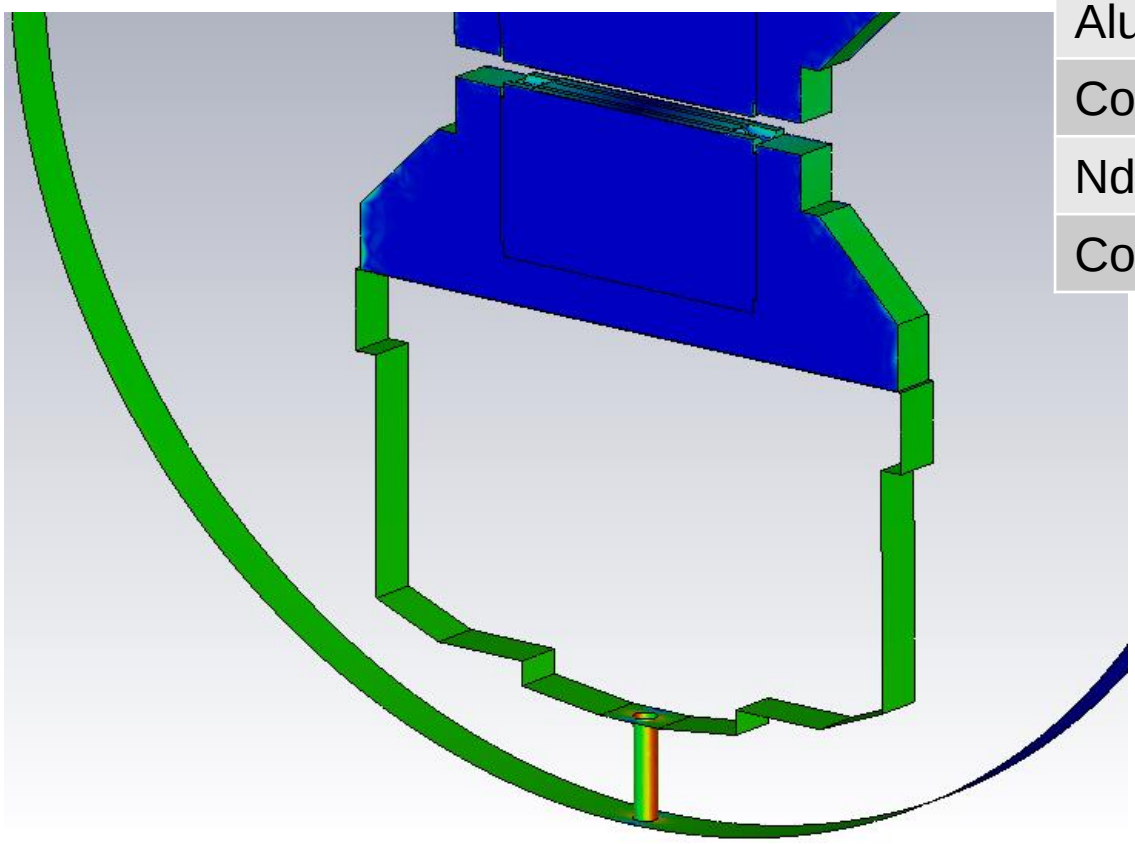
Geometry



Periodic Model

Surface current, losses

- Q=2900



	Losses
Steel	70%
Aluminum	22%
CoFeV	5%
NdFeB	3%
Copper	0.2%

Conclusion

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- Detailed model for PETRA-4 IVU's trapped mode analysis
- Resonance frequencies
  - Good agreement at smaller gaps
  - Worse agreement at larger gaps
- Quality factor
  - No agreement
  - Similar result for the SLAC-IVUs, PRAB 2019
- Open questions regarding the model
  - Material properties?
  - Ferrite dampers?
  - New experiments?