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Computation of Coupler Damping Properties in Concatenated Arrangements

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Universität Rostock - Institut für Allgemeine Elektrotechnik

HOM10 - Workshop
Cornell University, 11.10.2010

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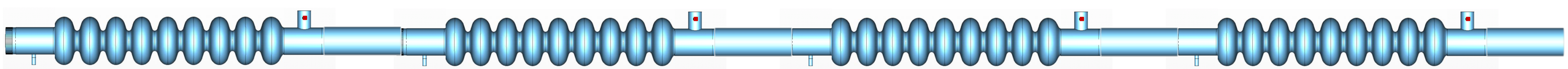
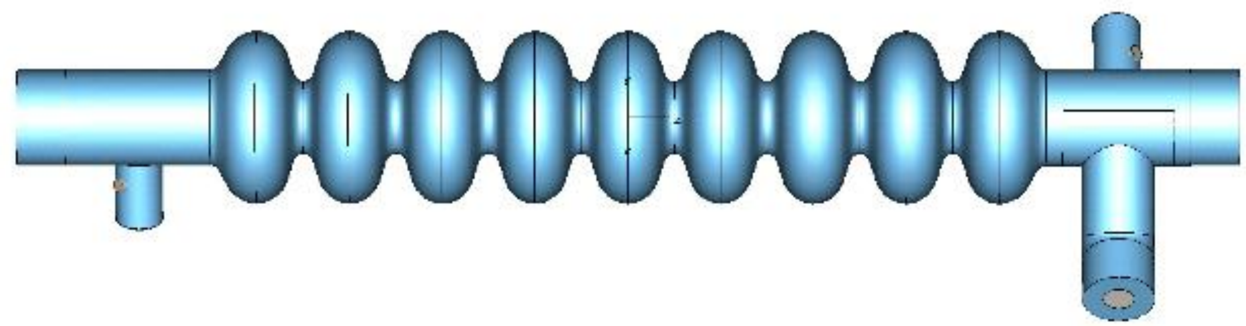
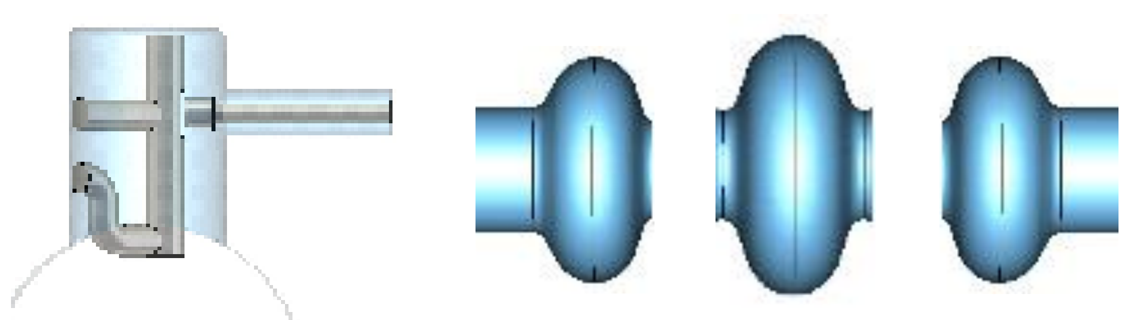
- A module ...

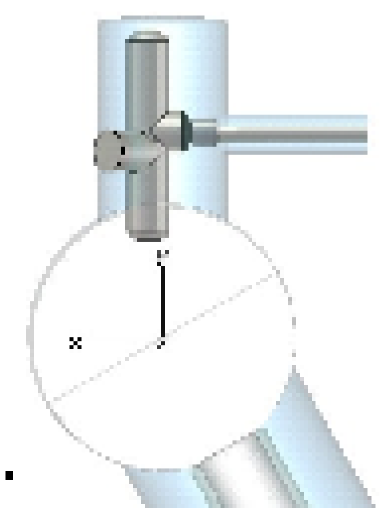


- ... consists of several cavities, ...



- ... which consists of several components,...





- ... that we should try to treat separately (as far as possible).

Overview:

- Who we are and what we are doing (30 sec)
- Use of scattering properties = S-parameters. Why and how?
- Experimental comparison: FNAL's 3rd Harmonic Module @ DESY
- How to extract loaded Qs
- Coupler design in terms of S-parameters
- Some ideas

DoHRo*, EUCARD**, CERN-SPL***-Study @ Rostock

DoHRo – HOM:*

-AP 1: HOM damping design for BERLINPRO

-AP 2: HOM damping design for ESS – high energy part of p-linac

-AP 3: Simplified electronics for HOM coupler signal based beam analysis

*EUCARD** – WP 10.5.3:*

HOM distribution and geometrical dependencies (FLASH-1.3, FLASH-3.9, XFEL(?)) needed for HOM coupler signal based beam analysis

*CERN-SPL***:*

HOM damping design for CERN-SPL-Study

*DoHRo: Dortmund-HZB-Rostock – "Innovative Technologien und Komponenten zukünftiger Teilchenbeschleuniger in Strahlungsquellen, funded by German Federal Ministry of Research+Education, Project 05K10HRC

**EUCARD: EU FP7 Research Infrastructure Grant No. 227579

***CERN-SPL: "Design of HOM-Damping for CERN-SPL"; funded by German Federal Ministry of Research+Education, Project: 05H09HR5

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DoHRo, EUCARD, CERN-SPL-Study @ Rostock

Staff (% of FTE): **Funding:**

Staff (% of FTE)	Funding
Prof. Ursula van Rienen (~ 5%) Dr. Dirk Hecht (administrative; now ~ 5%) Dipl.-Ing. Thomas Flisgen (80% EUCARD, 20% teaching)	Universität Rostock
Dr. Hans-Walter Glock	25% DoHRo 25% EUCARD 50% CERN-SPL
Dipl.-Ing. Mirjana Ivanovska (50%, on pregnancy leave till Nov`10) Dipl.-Phys. Tomasz Galek (50% July`10 – Dec`10) Dipl.-Ing. Korinna Brackebusch: (50%)	CERN-SPL
Dipl.-Ing. Korinna Brackebusch: (50%) Dr. Carsten Potratz (100%)	DoHRo

Thanks to all of them for contributions + discussions

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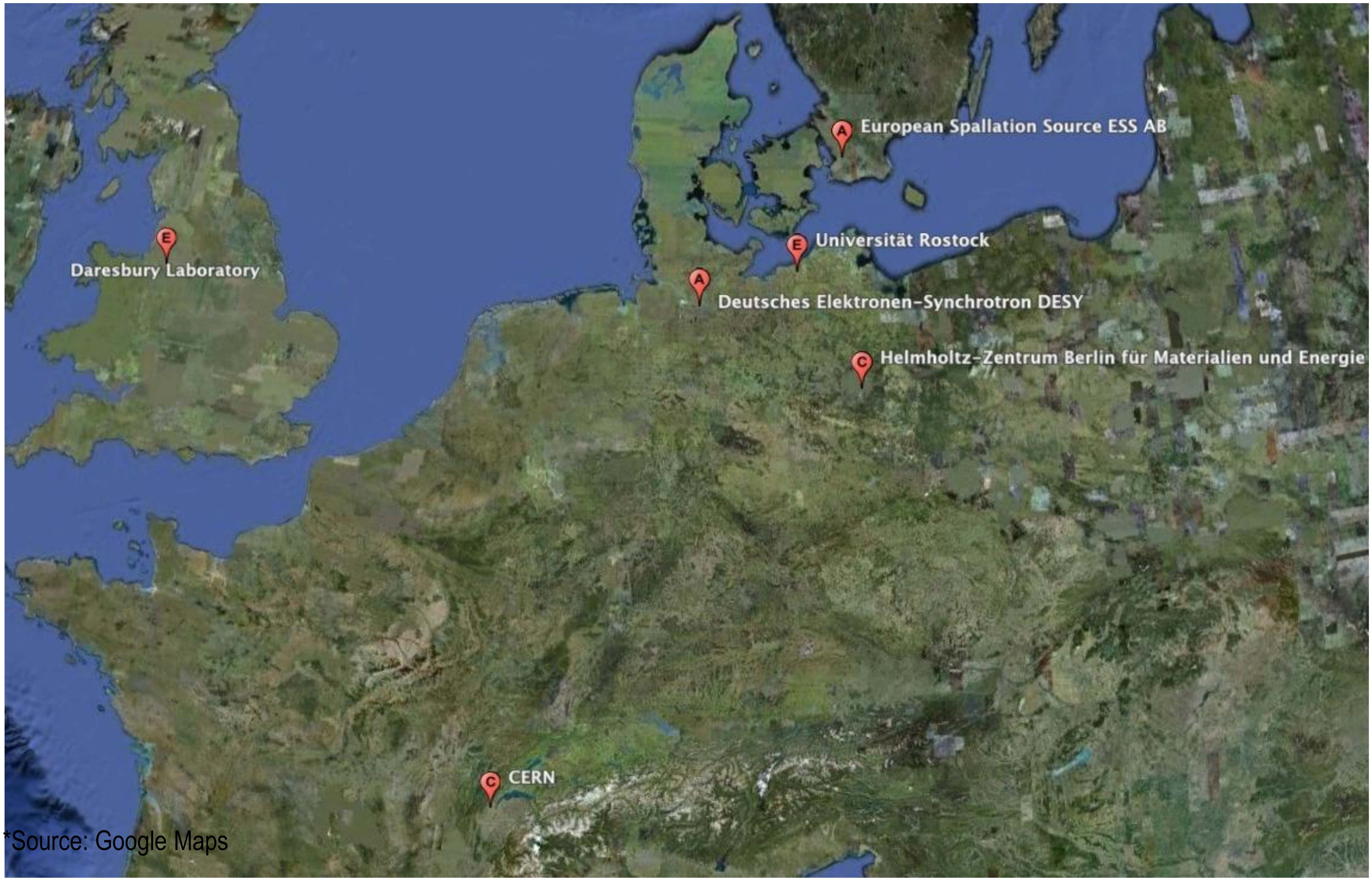
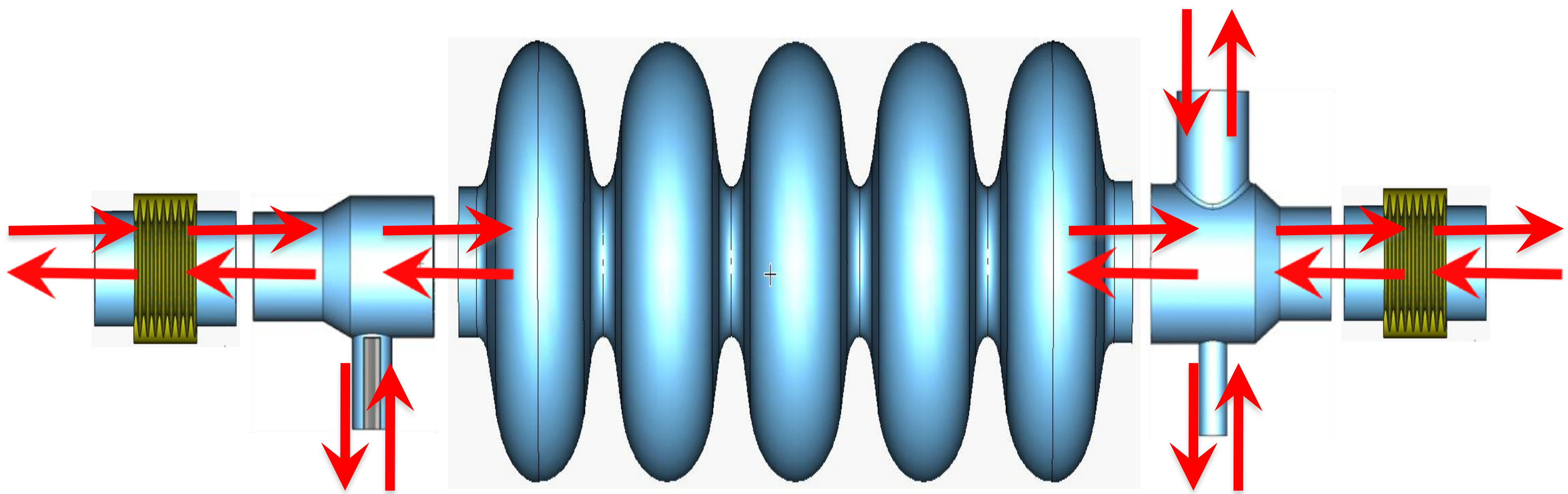


*Source: Google Maps

Concatenation procedure based on scattering properties: Coupled S-Parameter Computation = CSC



- Split structure in sections
- Compute scattering (S-) parameters of all sections individually with appropriate solvers
- Compute overall S-parameters as function of f with special algorithm*, applicable to any structure topology and mode number
- *: **e.g.:** H.-W. Glock, K. Rothemund, U. van Rienen: "CSC - A System for Coupled S-Parameter Calculations", TESLA-Report 2001-25 **or** K. Rothemund, H.-W. Glock, U. van Rienen: "Eigenmode Calculation of Complex RF-Structures using S-Parameters", IEEE Transactions on Magnetics, Vol. 36, (2000): 1501-1503 and references therein

Why description in terms of (multimodal) S-parameters?

- Waveguide mode amplitudes (complex-valued) of interfacing cross sections are a "canonical" set of variables, i.e. least number of variables for given precision
- Delivered by most codes (rotational 2D / 3D) (our workhorse: CST Suite)
- Measurable in single-mode, normalized impedance (usually 50 Ohms) regimes
- Simple analytical description of beam pipe = waveguide; rotations wrt. beam axis = rotation matrix according to non-monopole waveguide modes
- Appropriate both above and below cut-off

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Methods in CST for S-parameter computation

	Transient Solver Hexahedral Grid	Frequency Solver Hexahedral Grid	Frequency Solver Tetrahedral Grid	Fast Resonant Solver Hexahedral Grid
Pro	• Straight forward time stepping; broadband computation of S-Parameters via FFT. • Weak coupling between orthogonal modes in rotational symmetric structures.	• Appropriate for structures with high quality factors. • Weak coupling between orthogonal modes in rotational symmetric structures. • Nice for field distributions	• Appropriate for structures with high quality factors. • Less number of unknowns compared to hexahedral mesh • Fast solver available for tetrahedral grids.	• Appropriate both for structures with high quality factors and coupler-like set-ups. • Weak coupling between orthogonal modes in rotational symmetric structures. • Really fast
Contra	• (Too) many time steps are needed to reach steady state in structures of large time constants.	• Long computational time, since single run needed for every frequency sample.	• Strong artificial coupling between orthogonal modes in rotational symmetric structures (e.g. cavity), due to non symmetric grid.	• Significant violation of unitarity of S-matrices below cut-off

corrected both with a posteriori transformation and software update

Workflow

Structure

Set of Sub-Structures

S-matrix computation

(CST, HFSS, GPU-Discontinuos Galerkin, analytical, recycling, ...)

effort: minutes ... hours ... days

Concatenation

(own *Mathematica* package: import, interpolation, concatenation, derived quantities, export, visualization)

effort: seconds ... minutes

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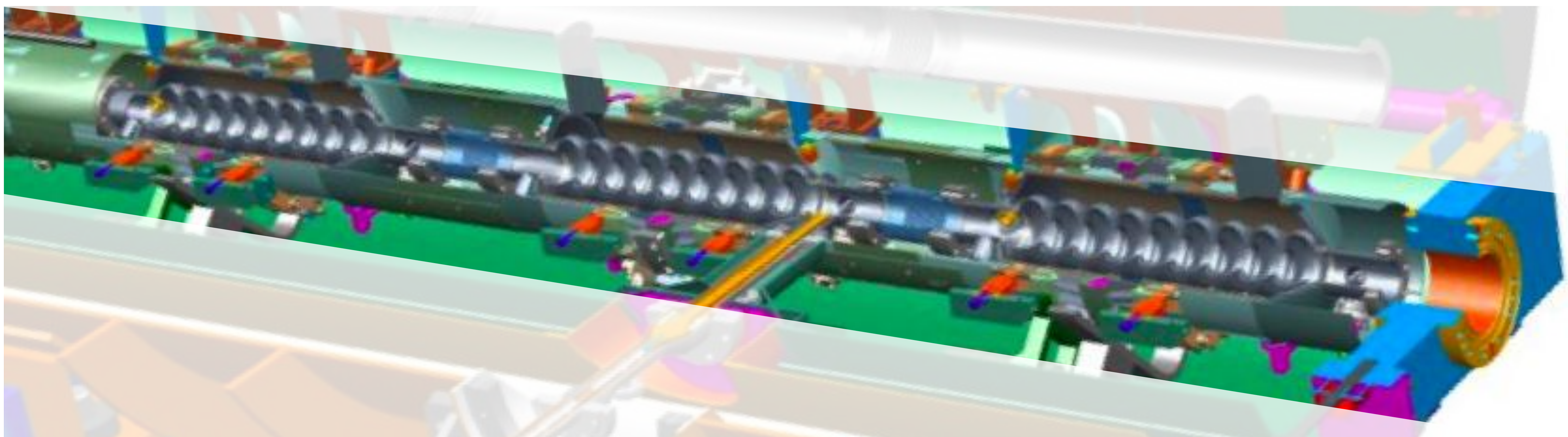
As an example:
Fermilab-build 3.9 GHz-3rd Harmonic Module @ FLASH

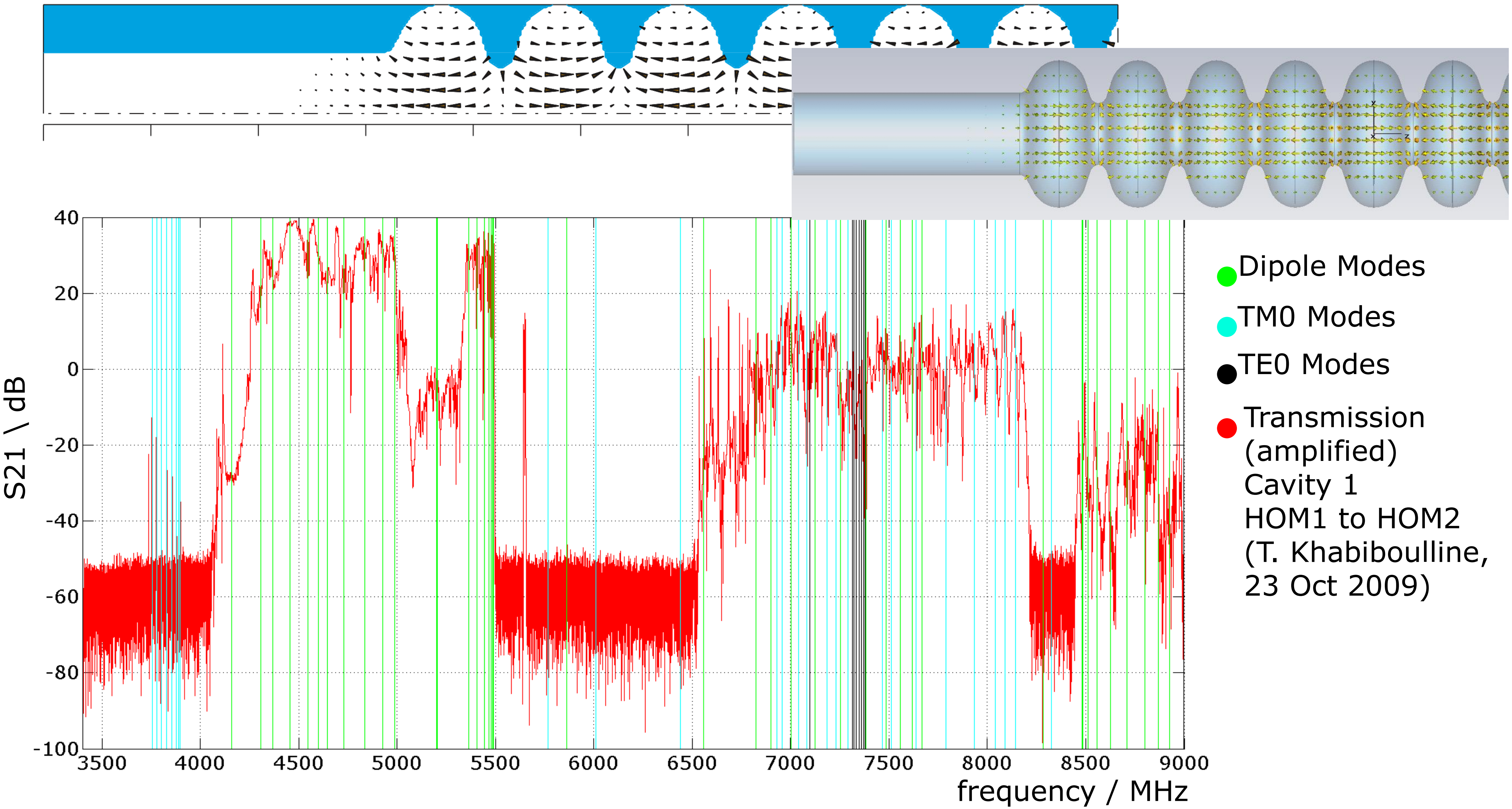


picture taken from: D. Mitchell, N. Solyak, T. Khabiboulline et.al., : "Mechanical Design and Engineering of the 3.9 GHz, 3rd Harmonic, SRF System at Fermilab", Poster presented at SRF03

Module of 4 x

9-cell-cavity, each: 1 power coupler, 2 HOM-coupler, 1 pickup

Single cavity eigenmode spectrum: CST Studio (3D) / MAFIA (2D)



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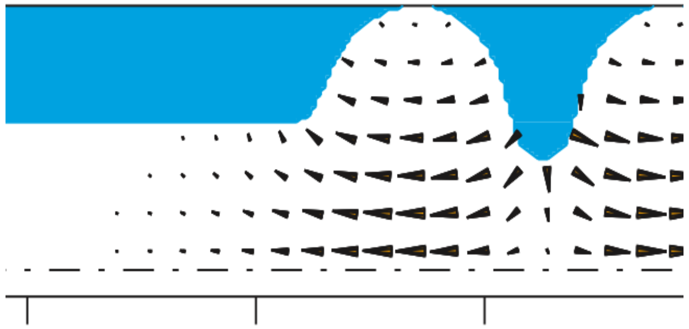
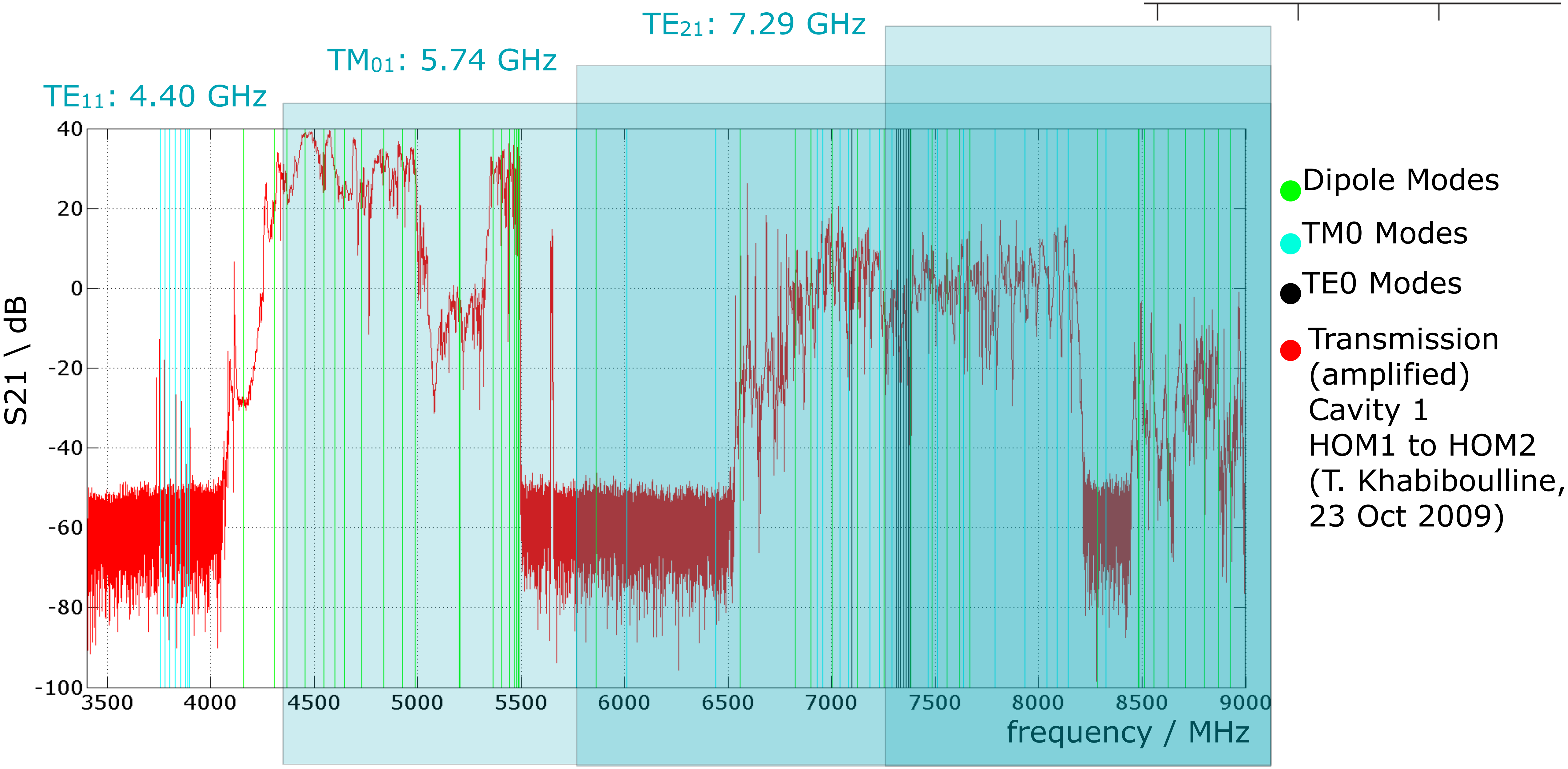
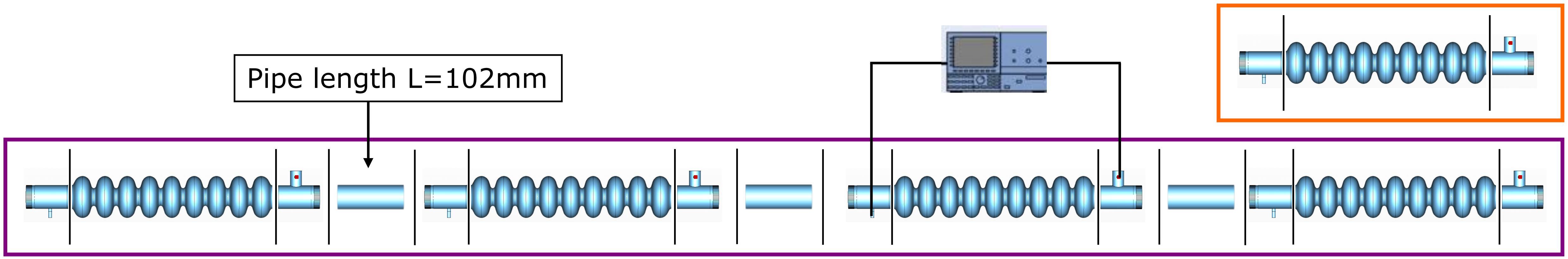
Specific: Large beam pipe diameter
=> almost everything propagating
=> computations on entire module

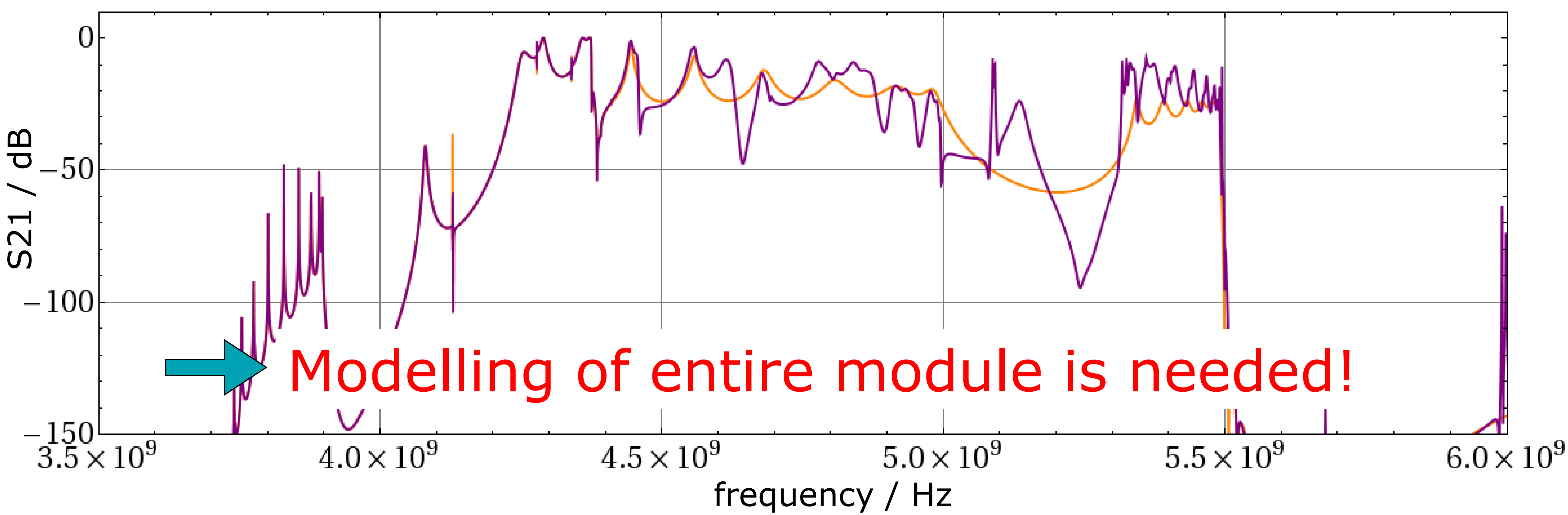




CSC-simulation @ 3rdHarm:

HOM-HOM transmission in module vs. single cavity





Modelling of entire module is needed!

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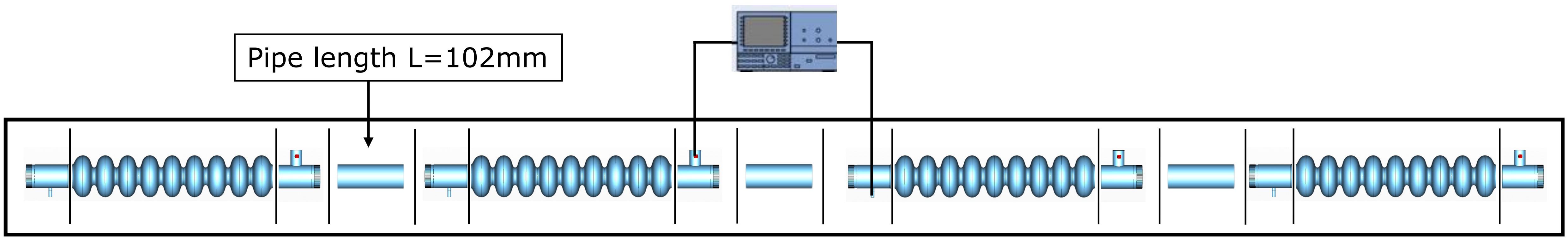
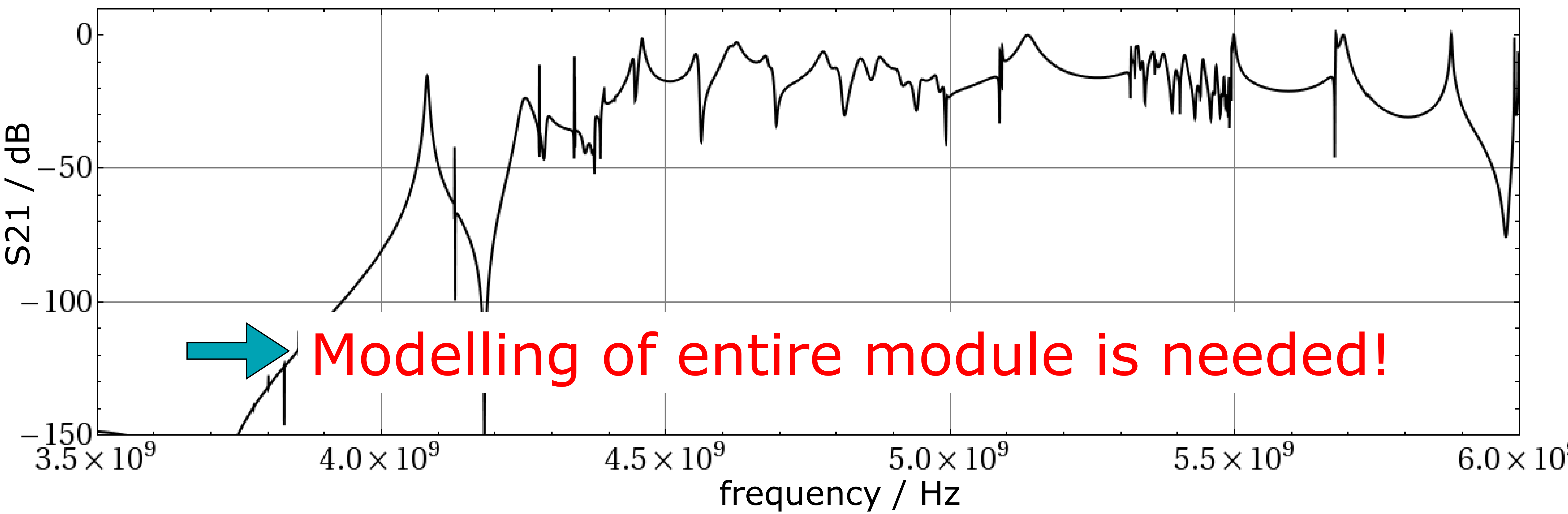
CSC-simulation @ 3rdHarm:

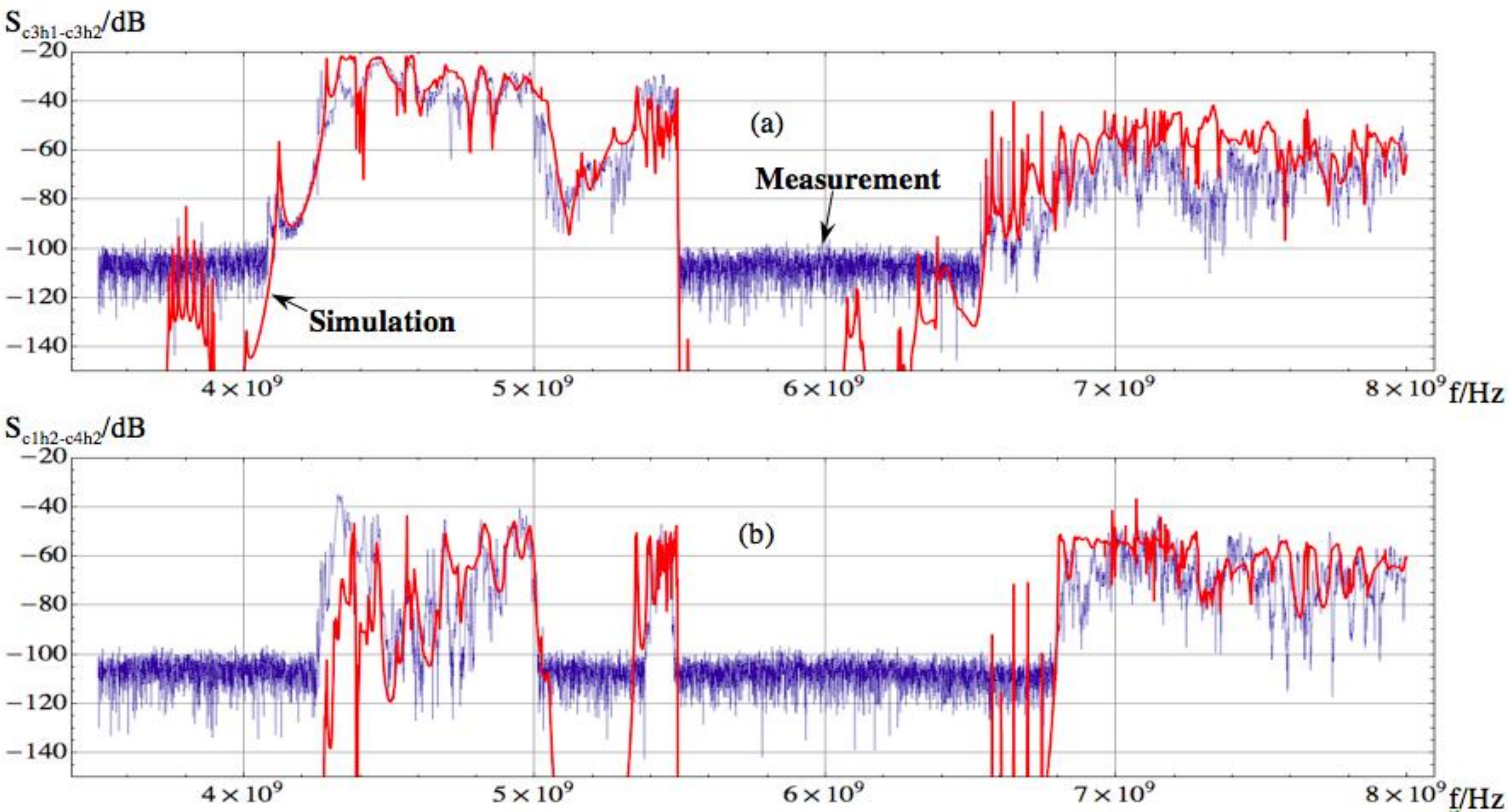
HOM to HOM transmission via beam pipe in module





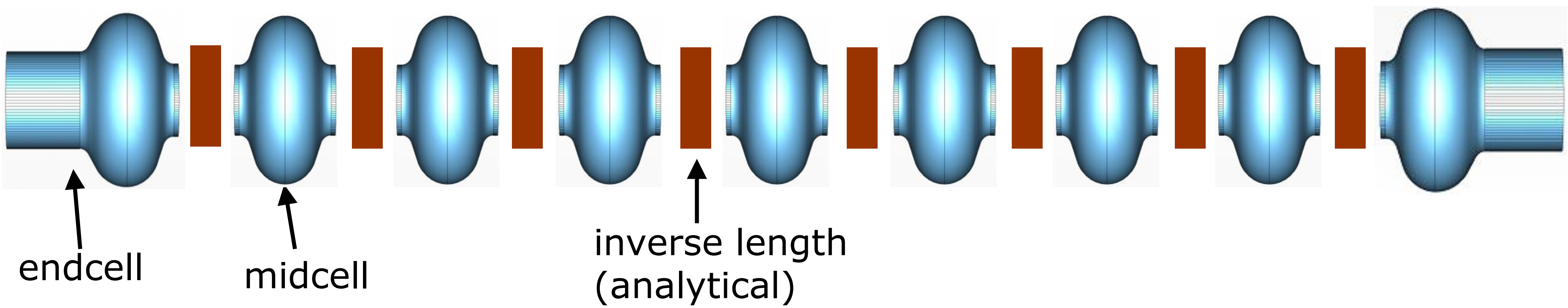
Modelling of entire module is needed!

CSC+Measurement @ 3rdHarm (IPAC`10, WEPEC052):
HOM-HOM transmission single cavity C3 and module start-end

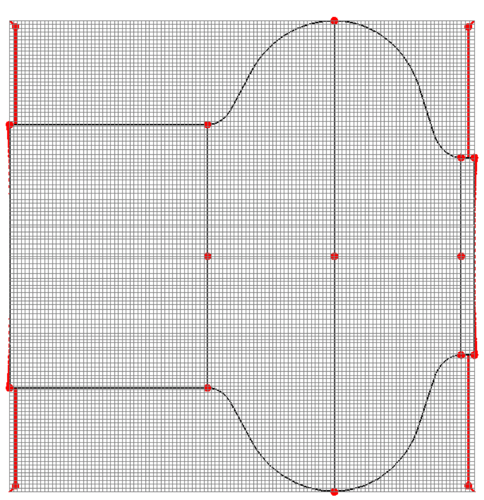


Nice, but not perfect – problems: cable calibration, main coupler, next modules ...

CSC-simulation@3rdHarm: Cavity composed of single cells

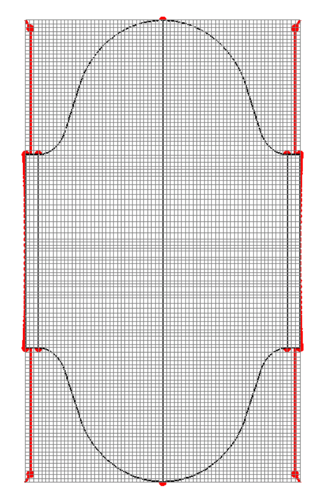


Endcell



- 3,090,528 hexahedral cells
- 8 modes excited in beam pipe
- 20 modes excited in cavity waist
- computing time*: 3h 5 min

Midcell

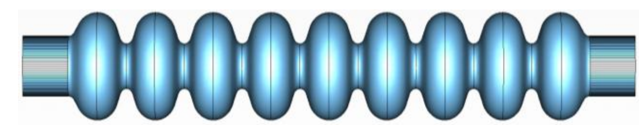


- 3,130,608 hexahedral cells
- 20 modes excited on both ports
- computing time*: 6h 18 min

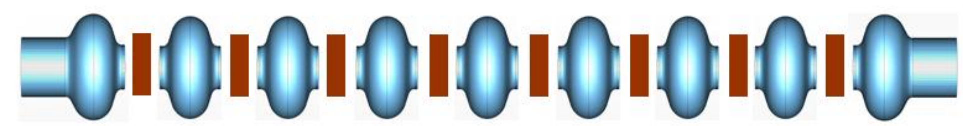
*using FR solver

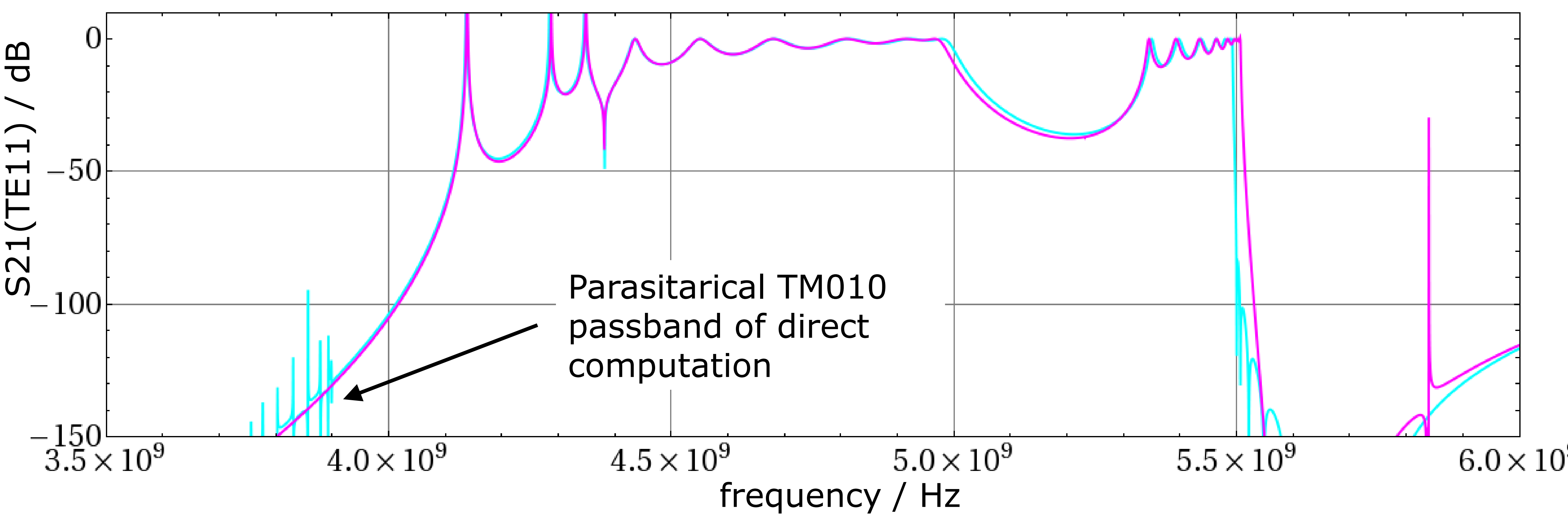
Transmission of TE11 dipole mode

Direct computation with N=8.12 Mio hexahedral meshcells, computing time FR solver: T=11h



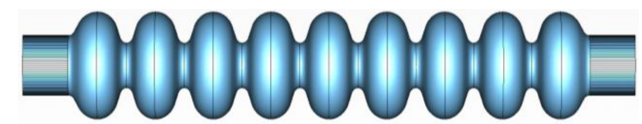
CSC coupling of mid- and endcell elements (only TE11 mode is considered), computing time CSC: couple of seconds



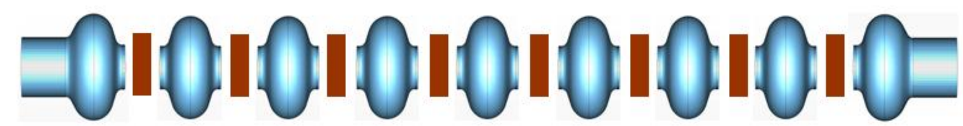


Transmission of TM01 monopole mode

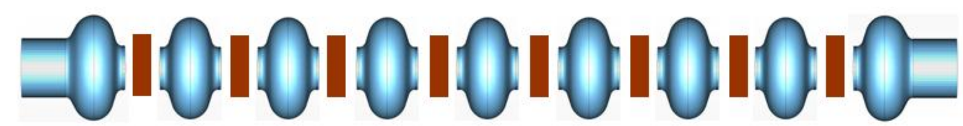
Direct computation with N=8.12 Mio hexahedral meshcells, computing time FR solver: T=11h

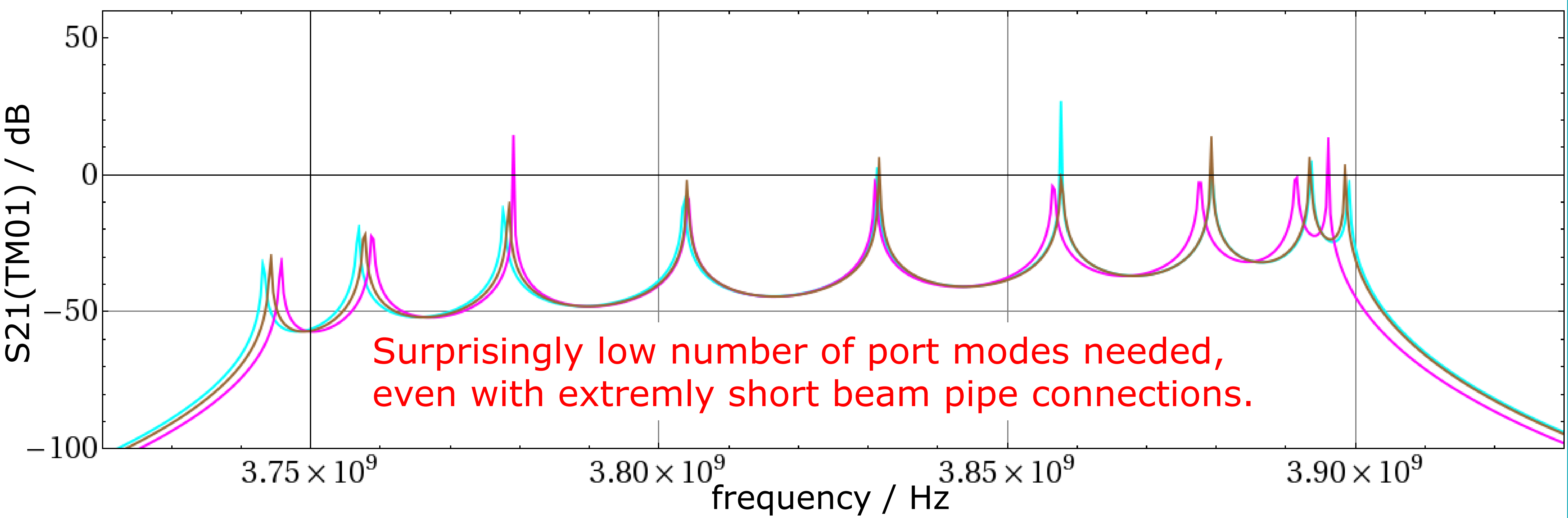


CSC coupling of mid- and endcell elements (only TM01 mode is considered)



CSC coupling of mid- and endcell elements (TM01 and TM02 modes are considered)





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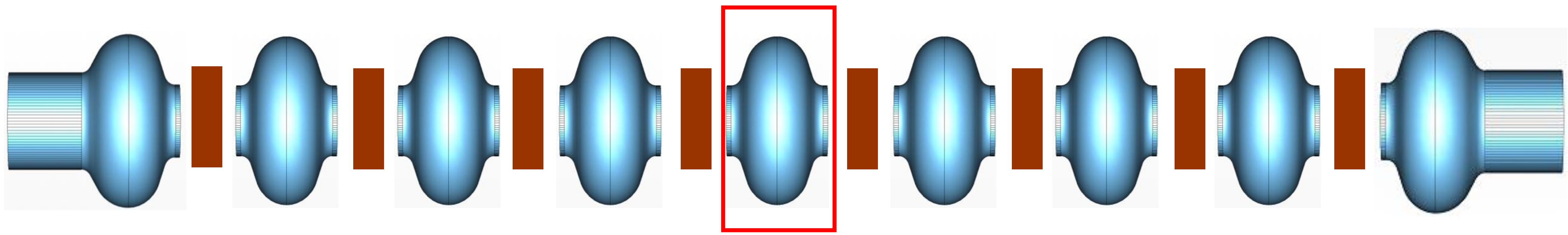
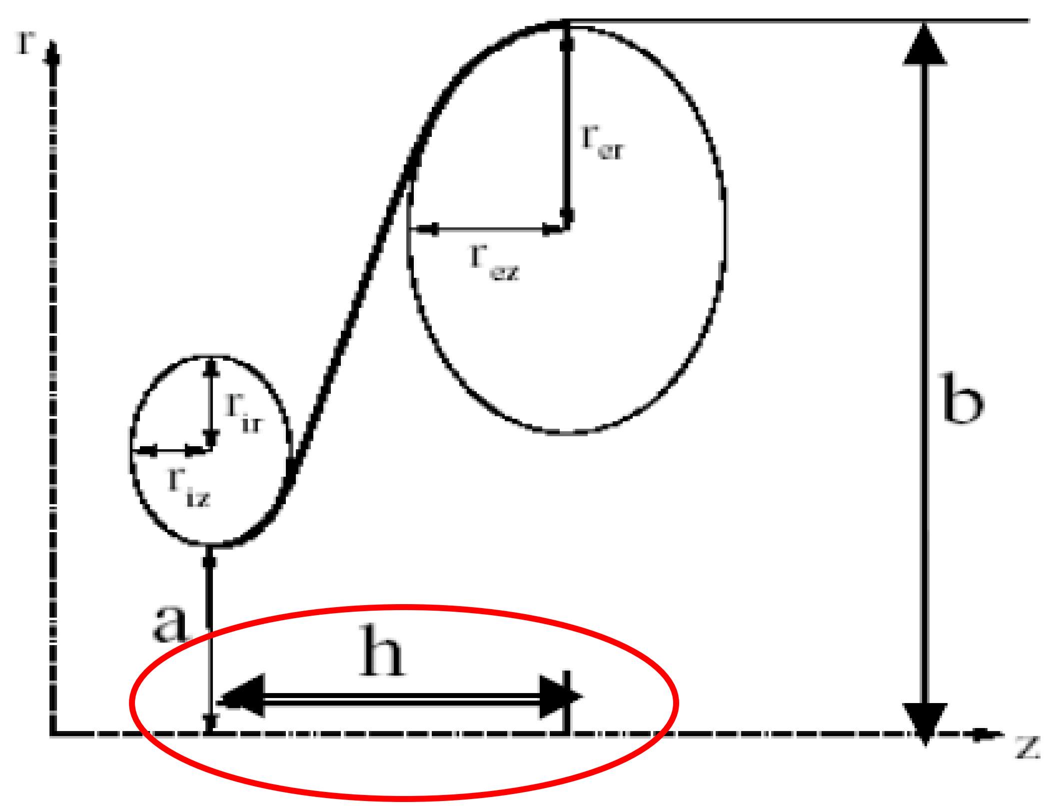
Geometry perturbations - example:

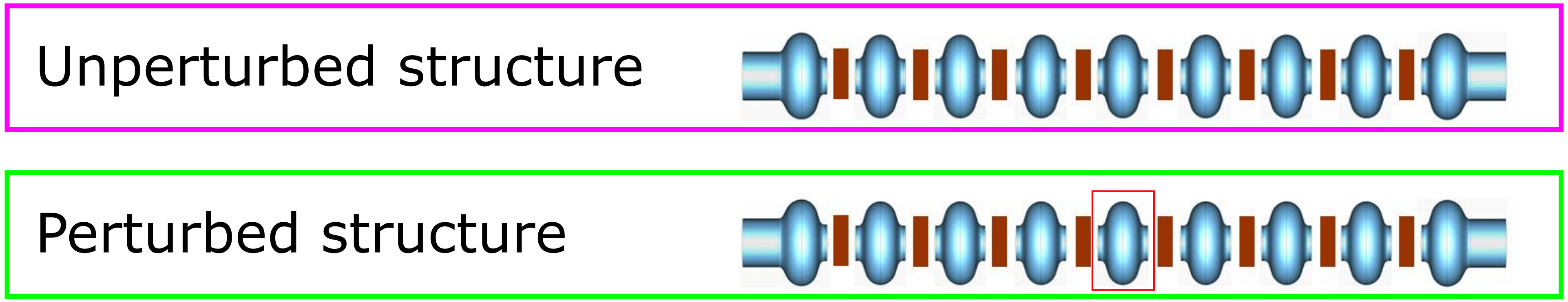
Effect of perturbed resonator in the middle of the cavity

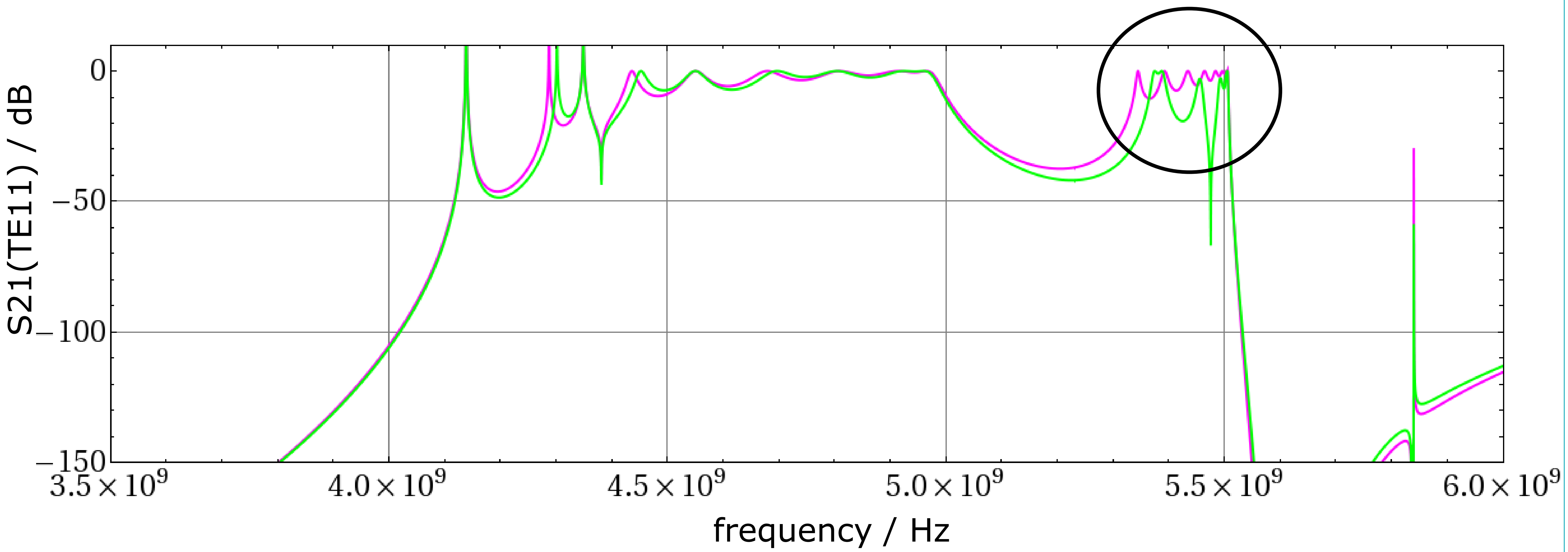




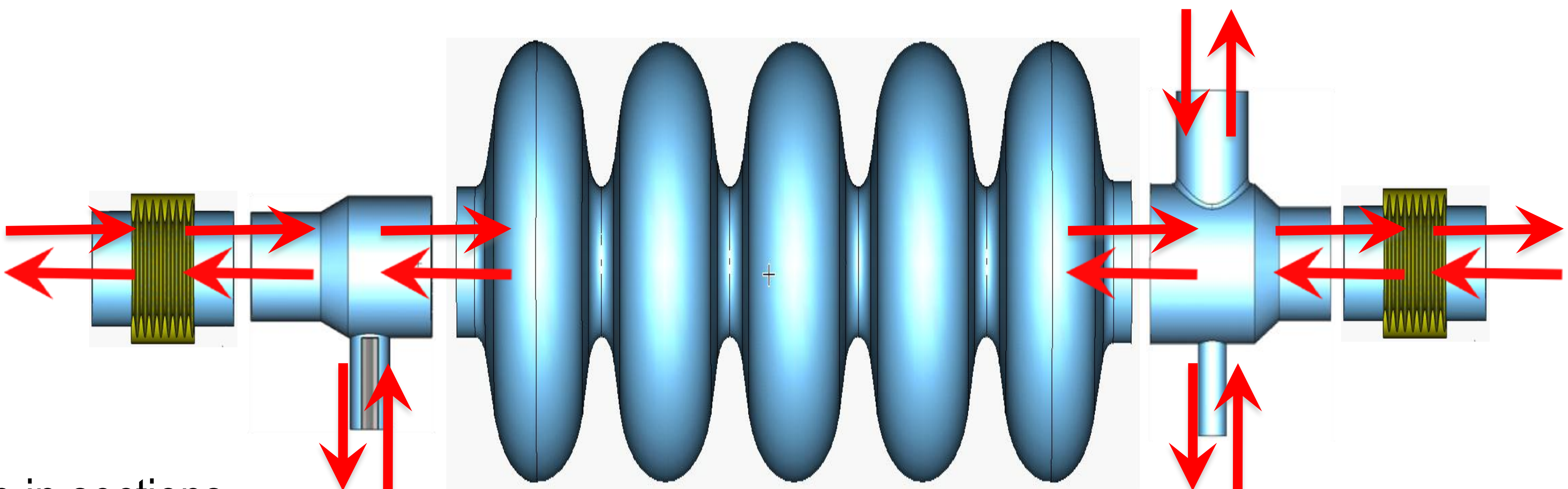
Length of mid cup h is 18.2167 mm instead of 19.2167 mm!

Effect of perturbed resonator on TE11 transmisson





Concatenation procedure based on scattering properties: Coupled S-Parameter Computation = CSC



- Split structure in sections
- Compute scattering (S-) parameters of all sections individually with appropriate solvers
- Compute overall S-parameters as function of f with special algorithm*, applicable to any structure topology and mode number
- Derive loaded Q-values from S-parameter spectra
- *: **e.g.:** H.-W. Glock, K. Rothemund, U. van Rienen: "CSC - A System for Coupled S-Parameter Calculations", TESLA-Report 2001-25 **or** K. Rothemund, H.-W. Glock, U. van Rienen: "Eigenmode Calculation of Complex RF-Structures using S-Parameters", IEEE Transactions on Magnetics, Vol. 36, (2000): 1501-1503 and references therein

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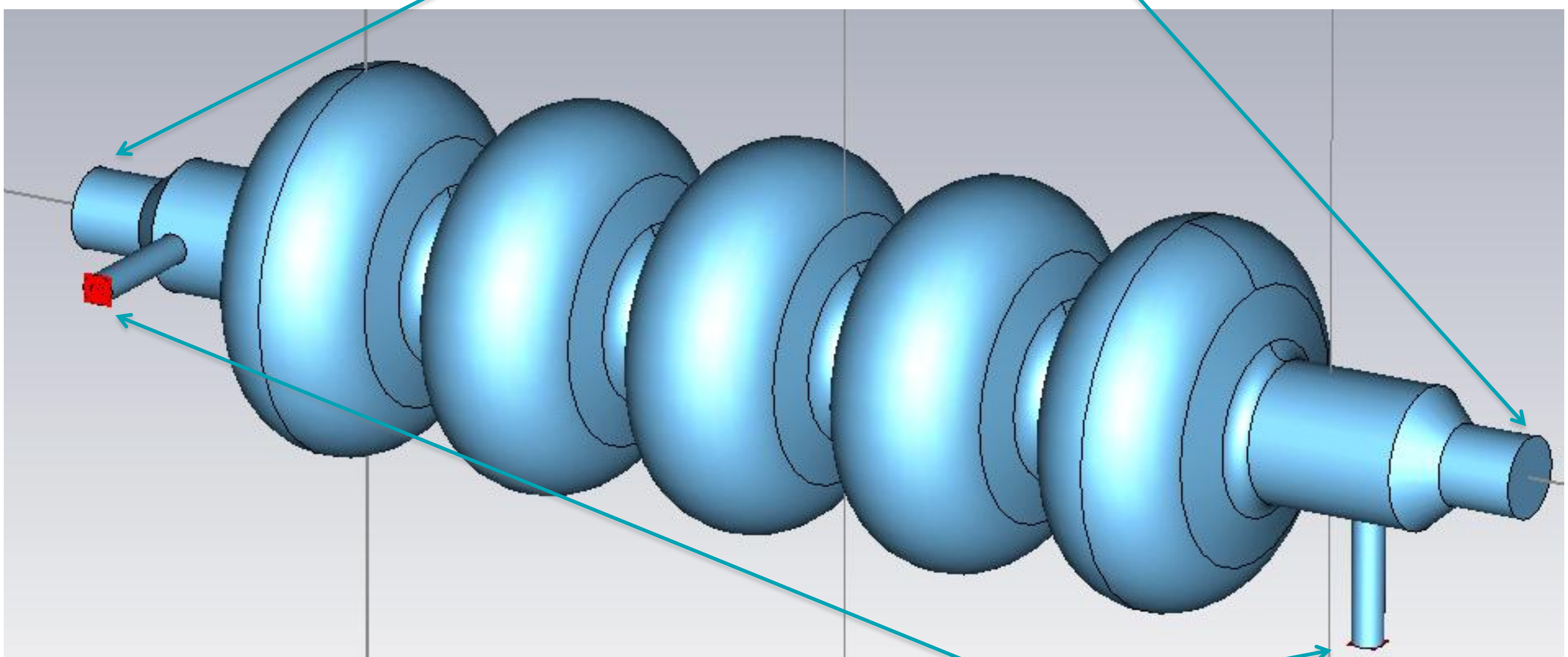
Example: SPL-β=1-cavity: HOM-Q_{load} from full setup computation of coax-coax-transmission

80 mm diameter shortened beam pipes



following Nov'09 SPL Meeting proposal: 30 mm diameter coaxial couplers

Do they provide sufficient HOM damping without fundamental mode filter?

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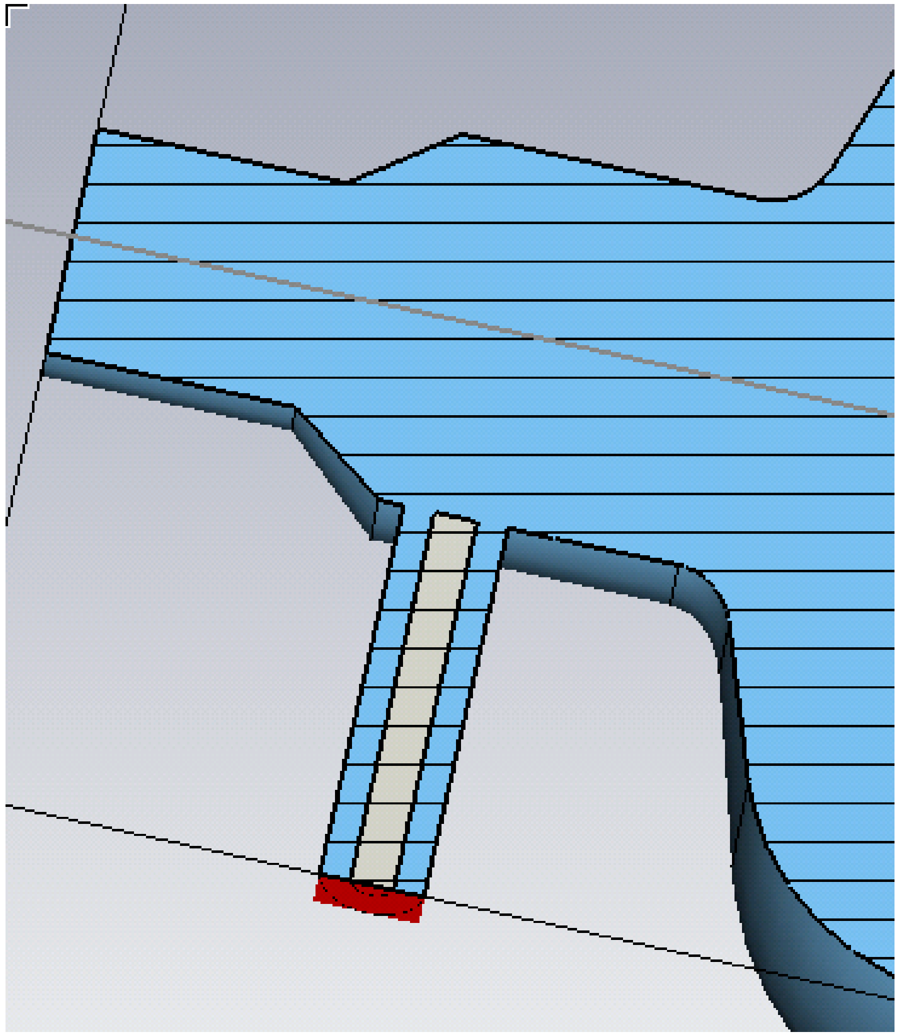
Coax with antenna tip depth = 0:

- to avoid extreme Q-values
- scaling in a second step using coupler section's S-parameters in order to reach design fundamental mode Q



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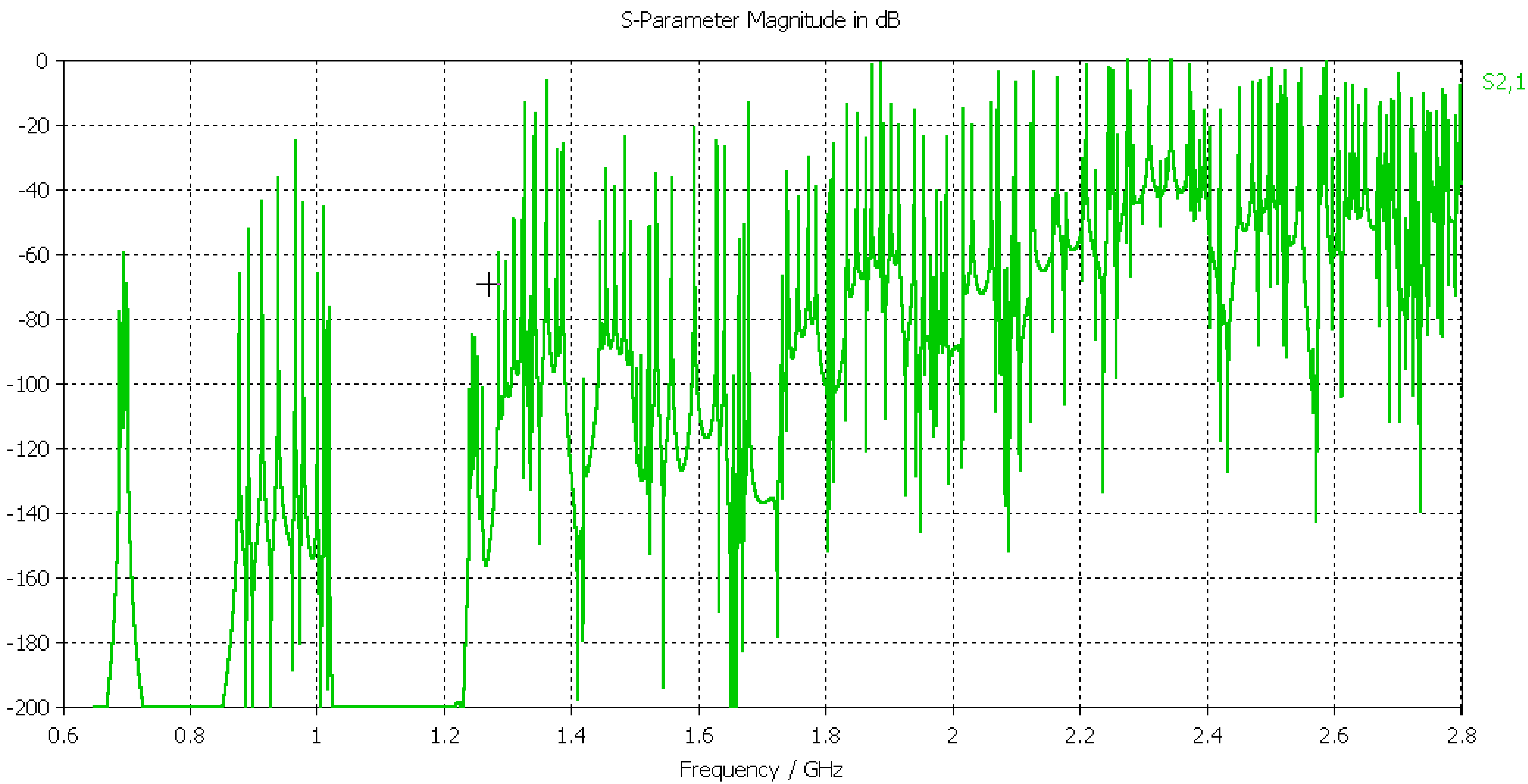
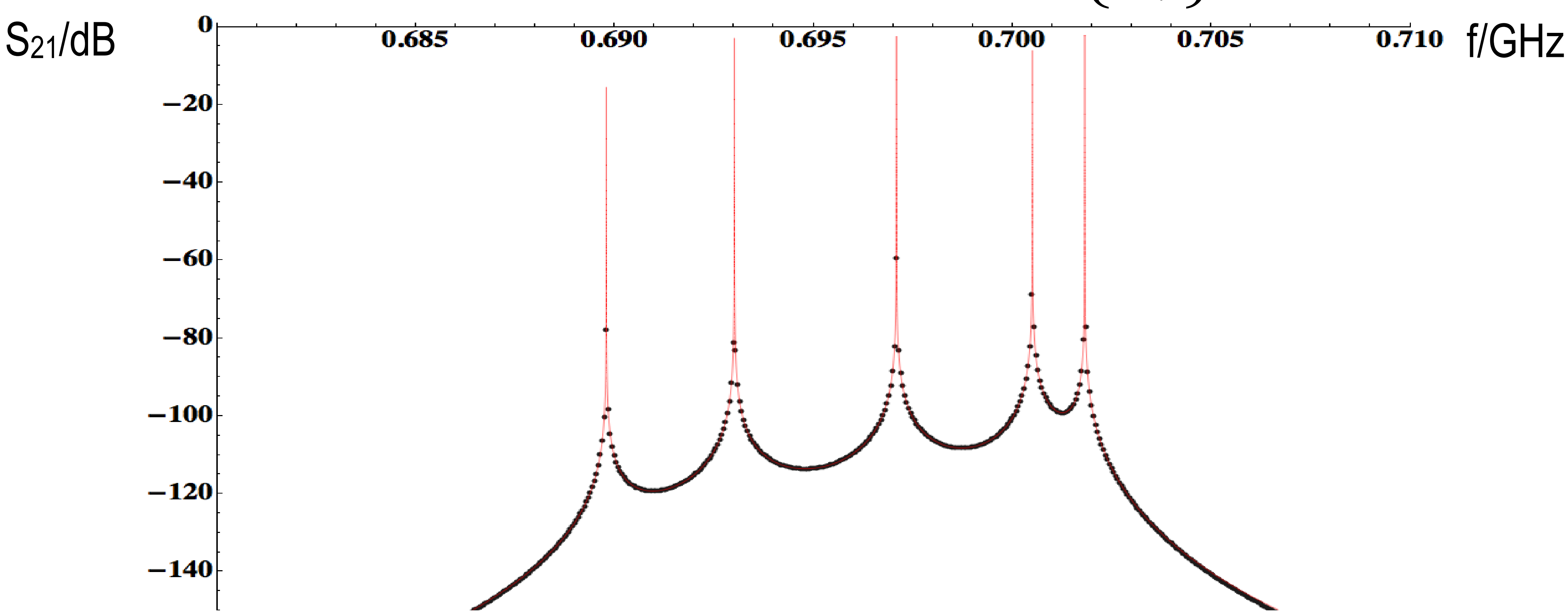
Entire transmission spectrum 0.65 – 2.80 GHz:
- more than 400 resonances with wide Q-range



Using Pole-fitting algorithm* to determine loaded Q's

$$S_{21}(f) = \sum_k \frac{a_k}{2\pi i f - p_k} \qquad Q_k = -\frac{\mathrm{Im}\{p_k\}}{2\,\mathrm{Re}\{p_k\}}$$



fundamental mode passband - dots: cstStudio© computation - line: fit result

*: Hecht, Rothemund, Glock, van Rienen: "Computation of RF properties of long and complex structures", Proc. EPAC 2002

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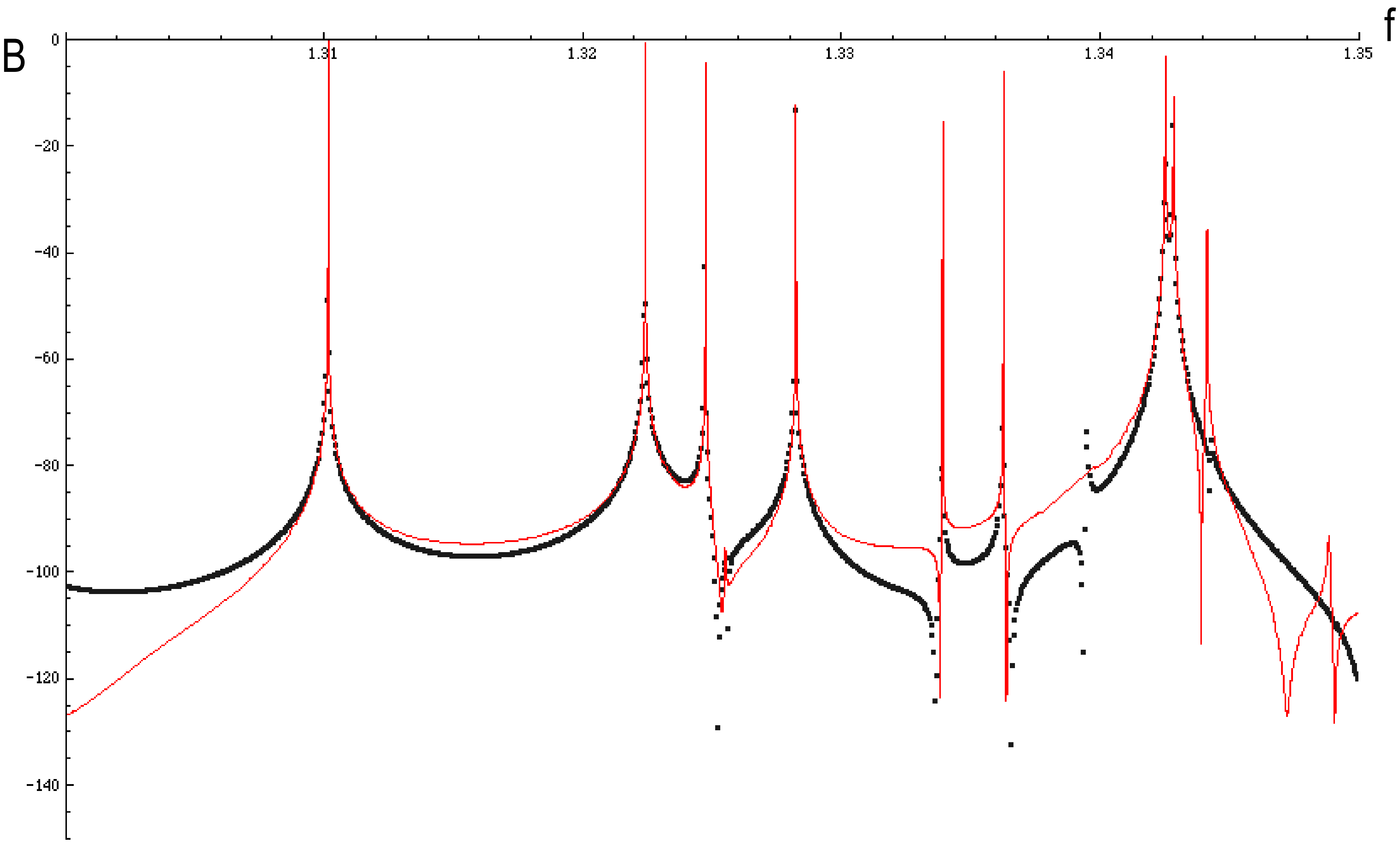
Pole-fitting algorithm: "Old" version



"Old" algorithm (see reference)

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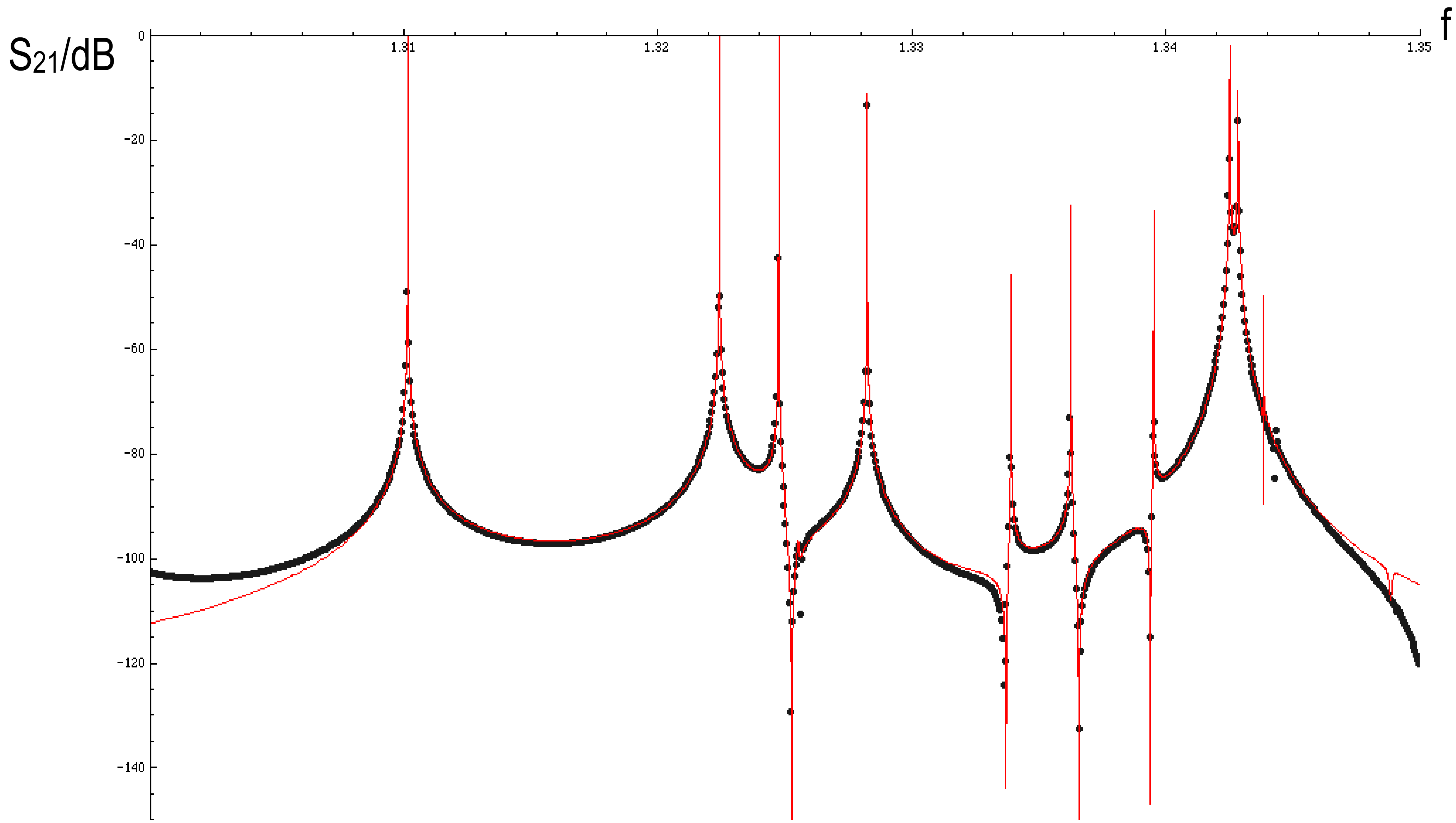
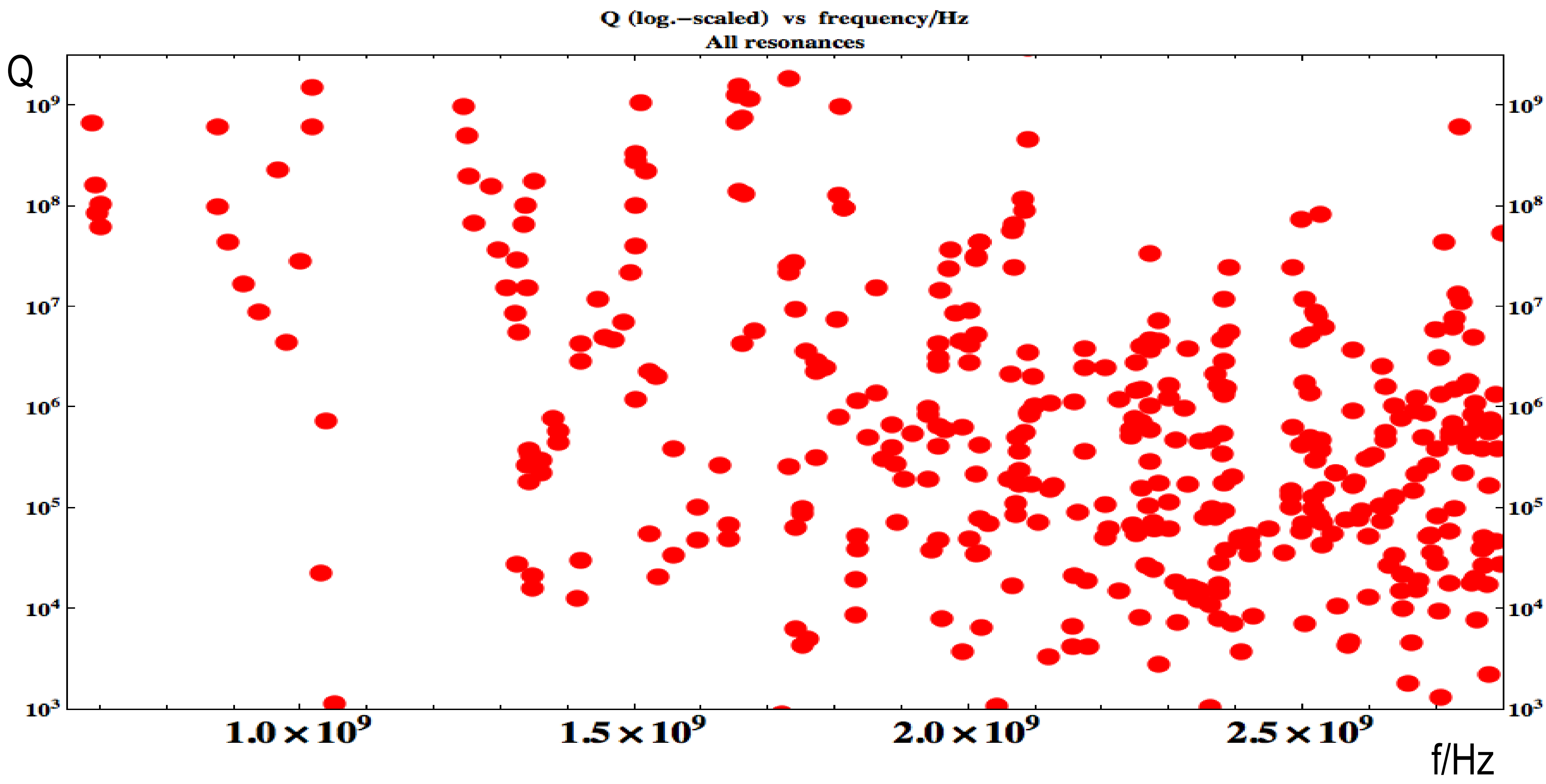
Improved pole-fitting algorithm



Improved algorithm* - corrects for higher order contributions (but still not working in any case)

*: Glock, Galek, Pöplau, van Rienen: "HOM spectrum and Q-factor estimations of the high-beta CERN-SPL-cavities", Proc. IPAC2010, WEPEC008

Q-value spectrum for 0 mm antenna depth:



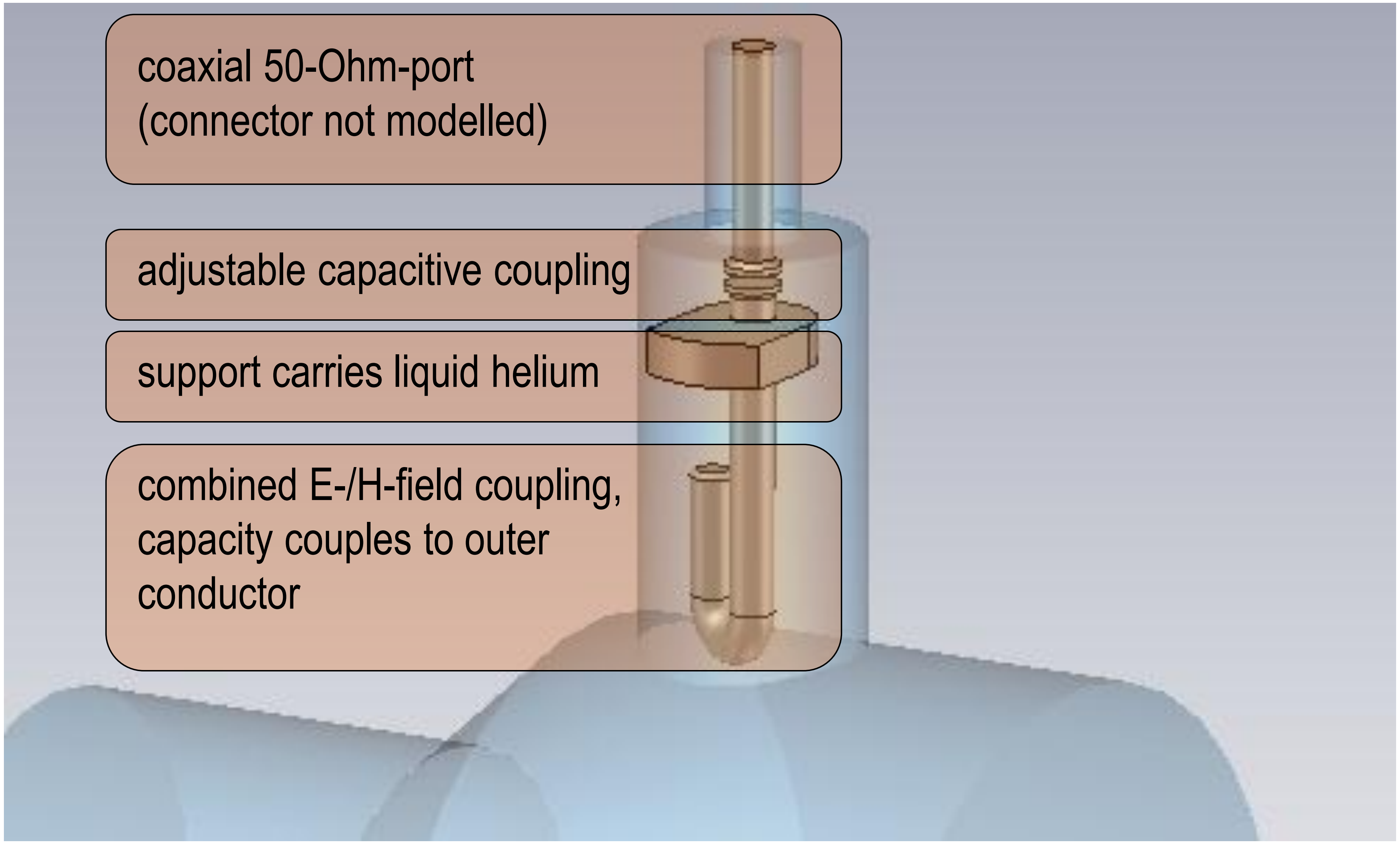
Several HOM modes with Q values as high or above fundamental mode (holds also for reduced coupling) **–**

Couplers without filters are not an acceptable solution!

Coupler optimization in terms of scattering properties

- Try to improve beam-pipe-coax coupling everywhere ...
- ... except for TM01 @ fundamental mode frequency: notch filter
- Example CERN-SPL: 704.4 MHz, 36 mm coupler diameter, demountable, classical hook prefered

"Classical" LEP hook design as starting point (priv.com. WW)



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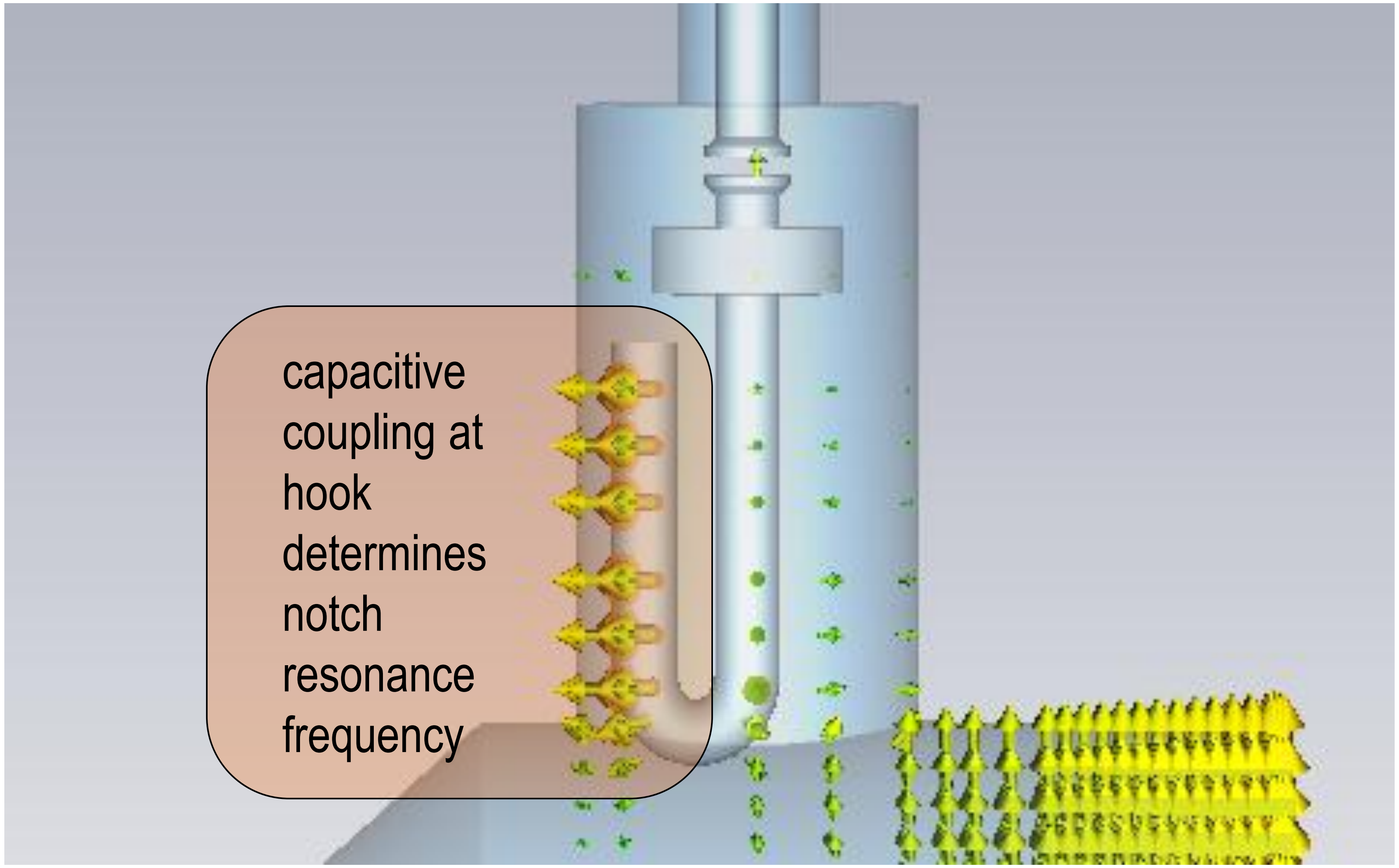
E-field geometry @ 704 MHz



strong capacitive coupling between "hook" and outer conductor

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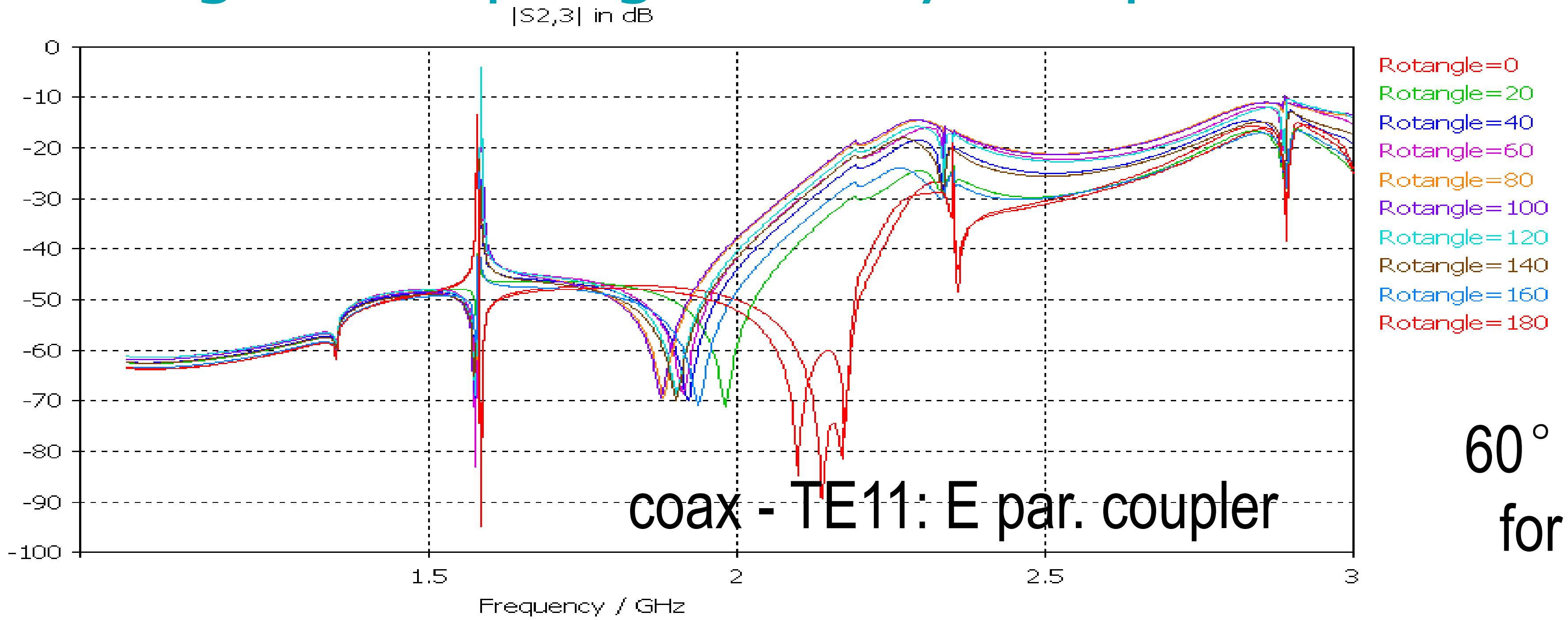
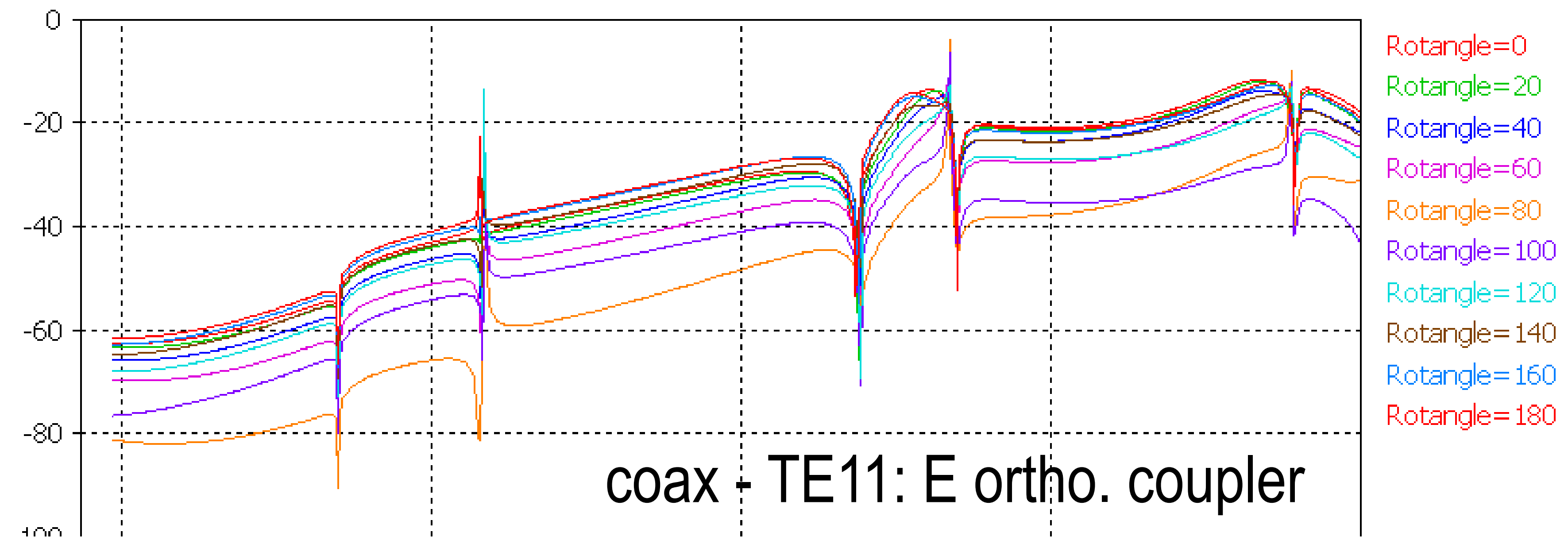
Waveguide-Coax-Transmission used to assess coupling – e.g. example geometry - dependence on hook rotation



60° good compromise for both polarizations



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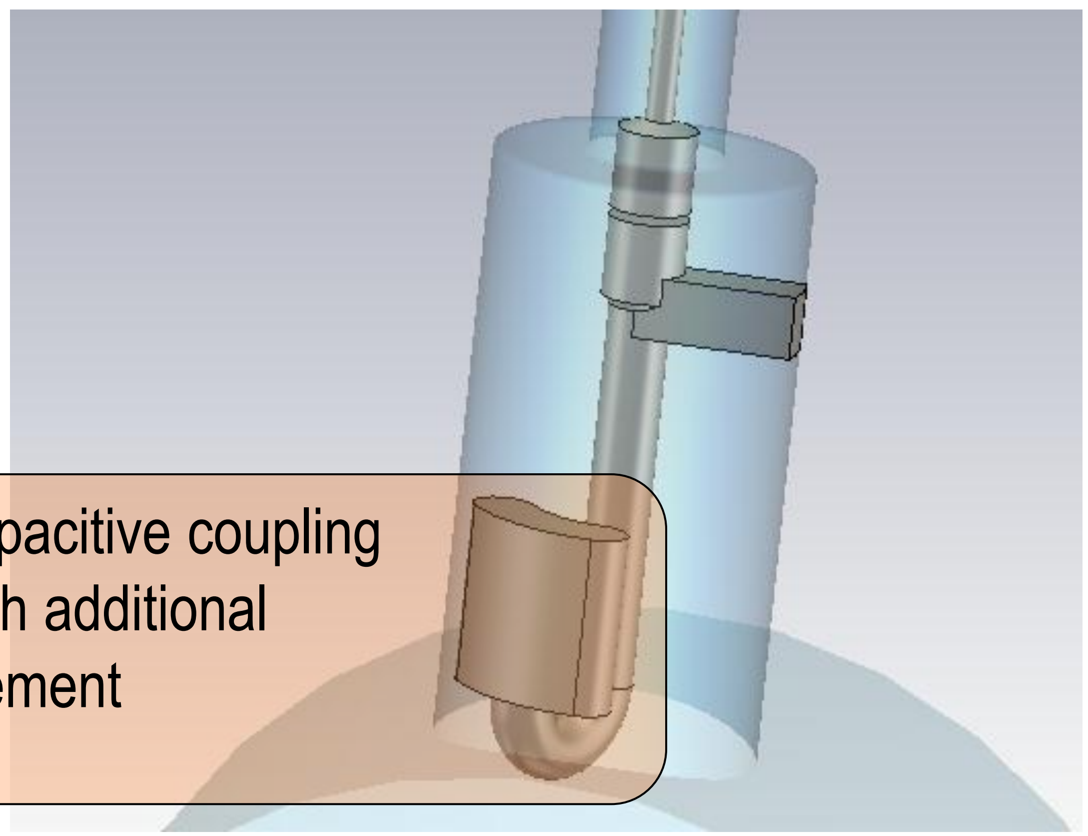
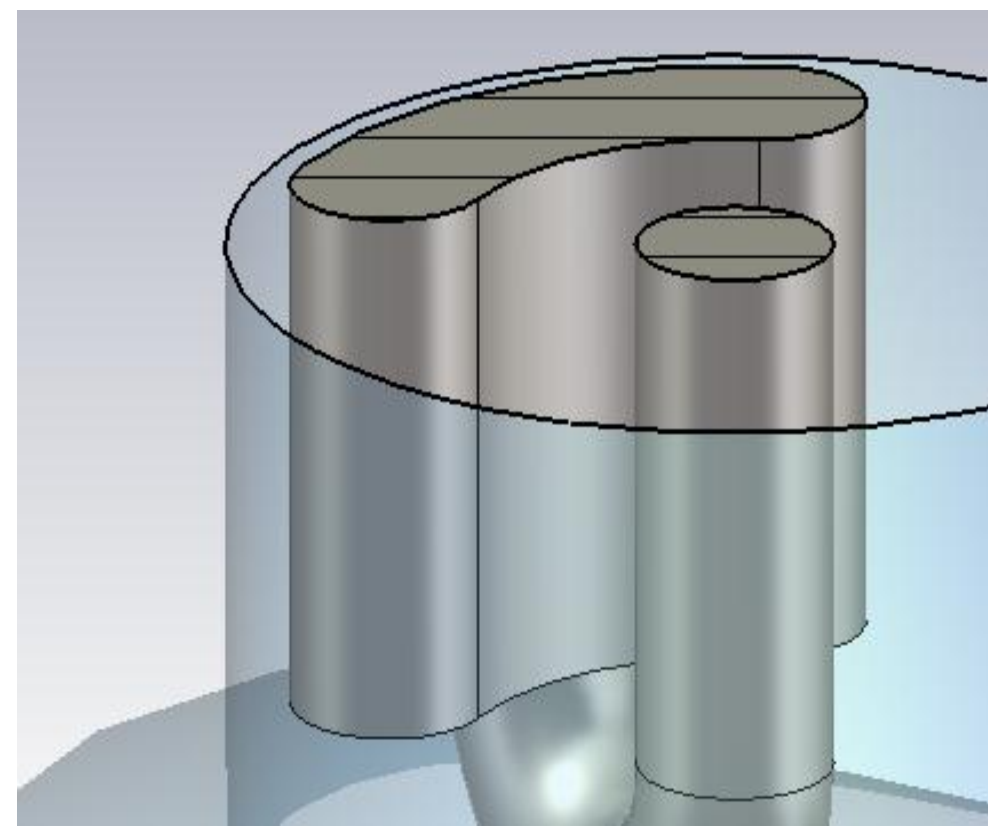
Pure hook (36 mm diam.) not tunable for 704 MHz => Modification of hook end to adjust fundamental mode filter





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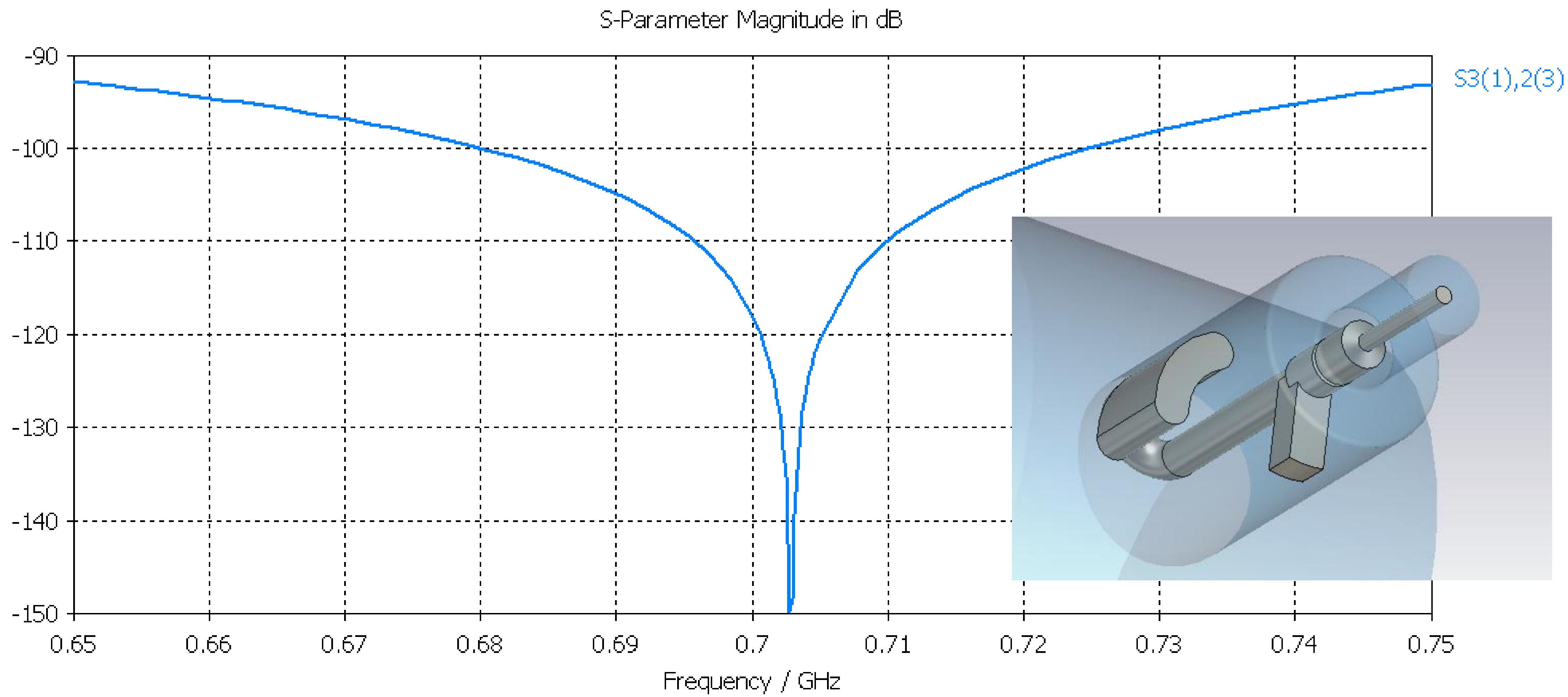
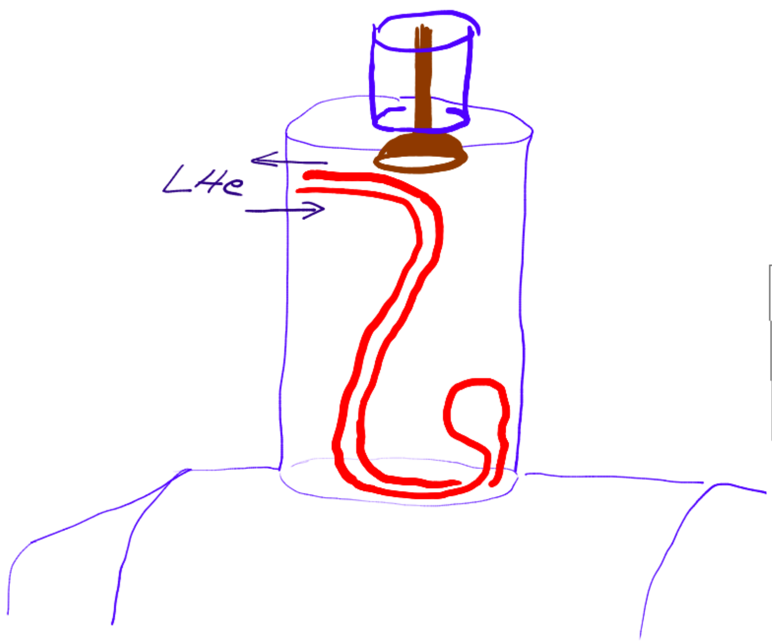
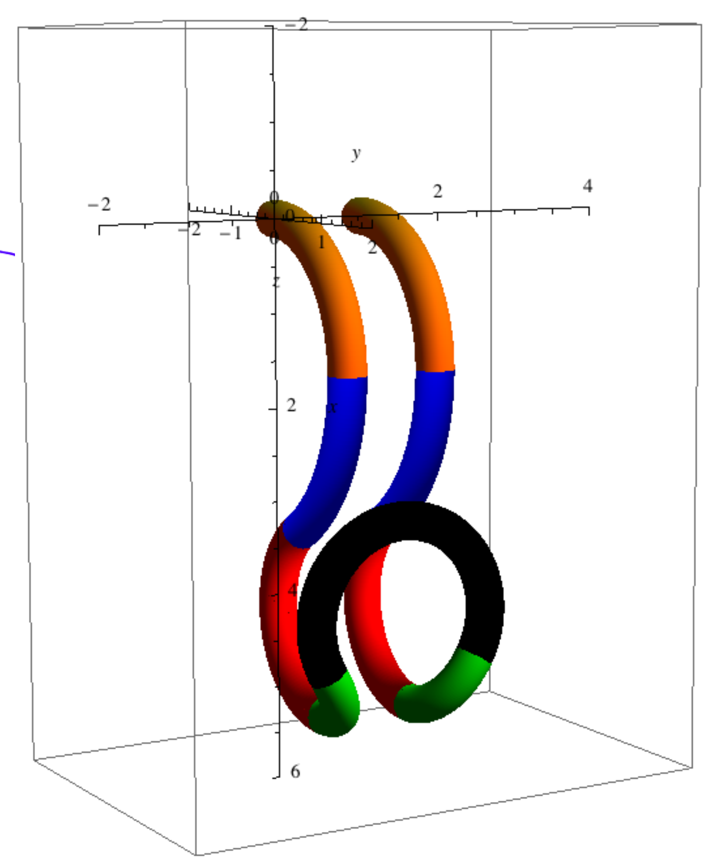
Waveguide(TM_0)–Coax–Transmission blocked @ fundamental mode frequency => Tuning ok

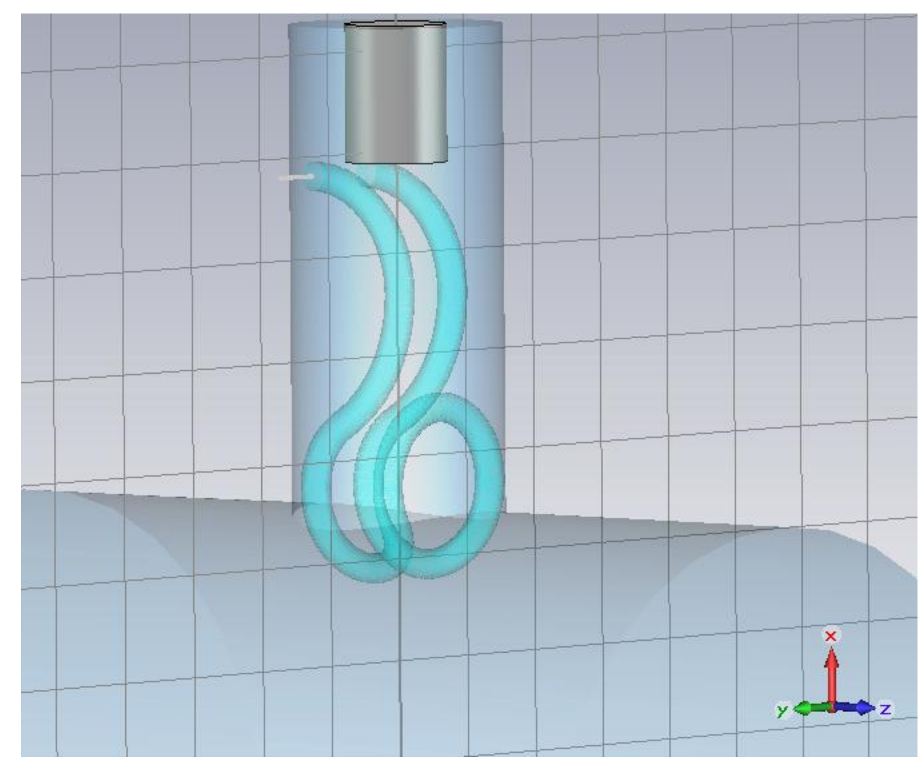


but: cooling + construction to be checked

Very recent idea: Coupler loop with LHe flow







coupler loop as sequence of circular bends

but: no computation/tuning yet; construction to be checked – please comment

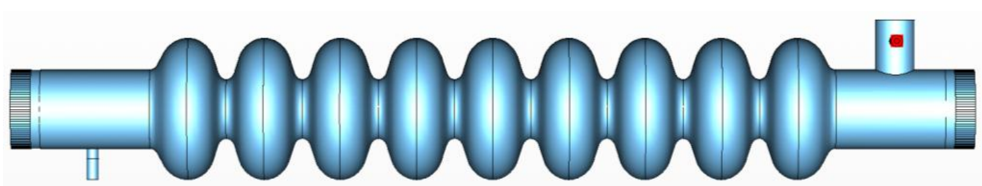
Thank you.

Reserve

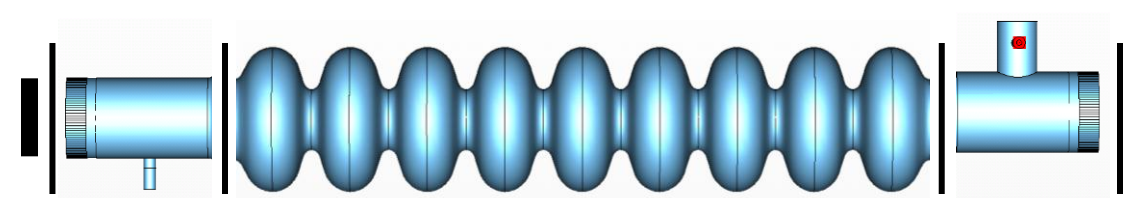
- CSC validation example
- Effect of shortened beam pipes on spectrum

Validation procedure of CSC using a benchmark structure

Computation of S-Parameters of complete benchmark structure



Element-wise computation of S-Parameters



Coupling of elements via CSC procedure

Comparison of S-Parameters

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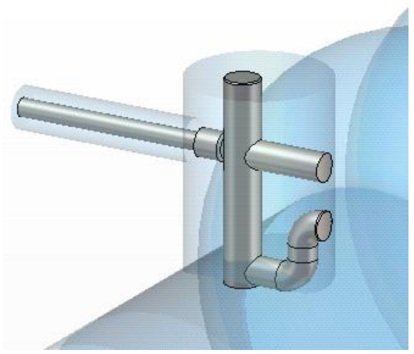
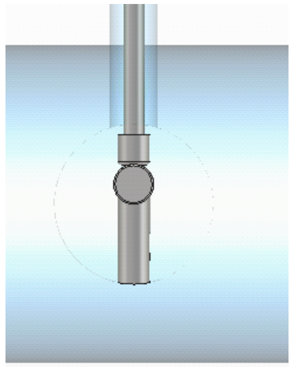
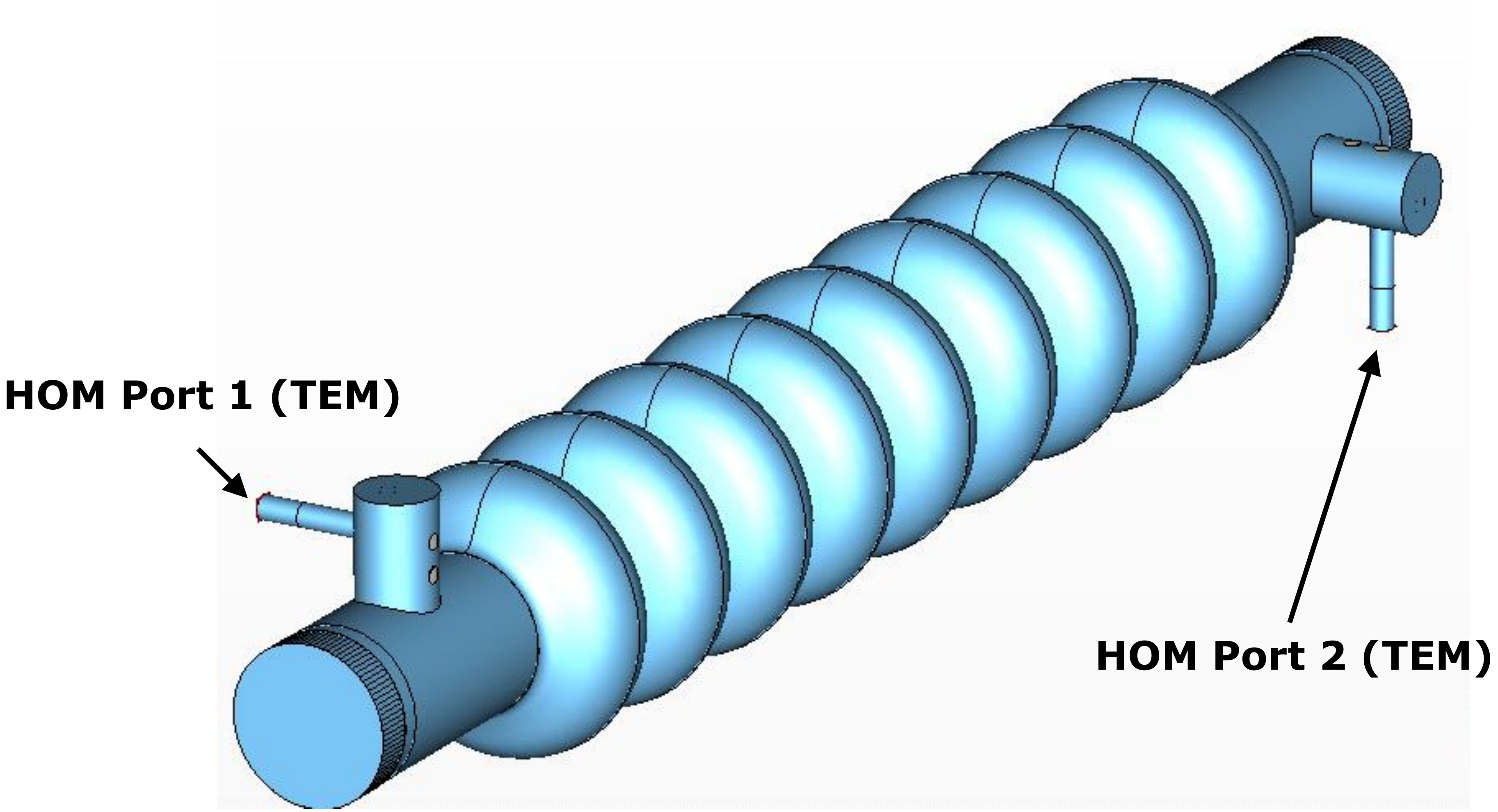
Validation of CSC using a simplified benchmark structure



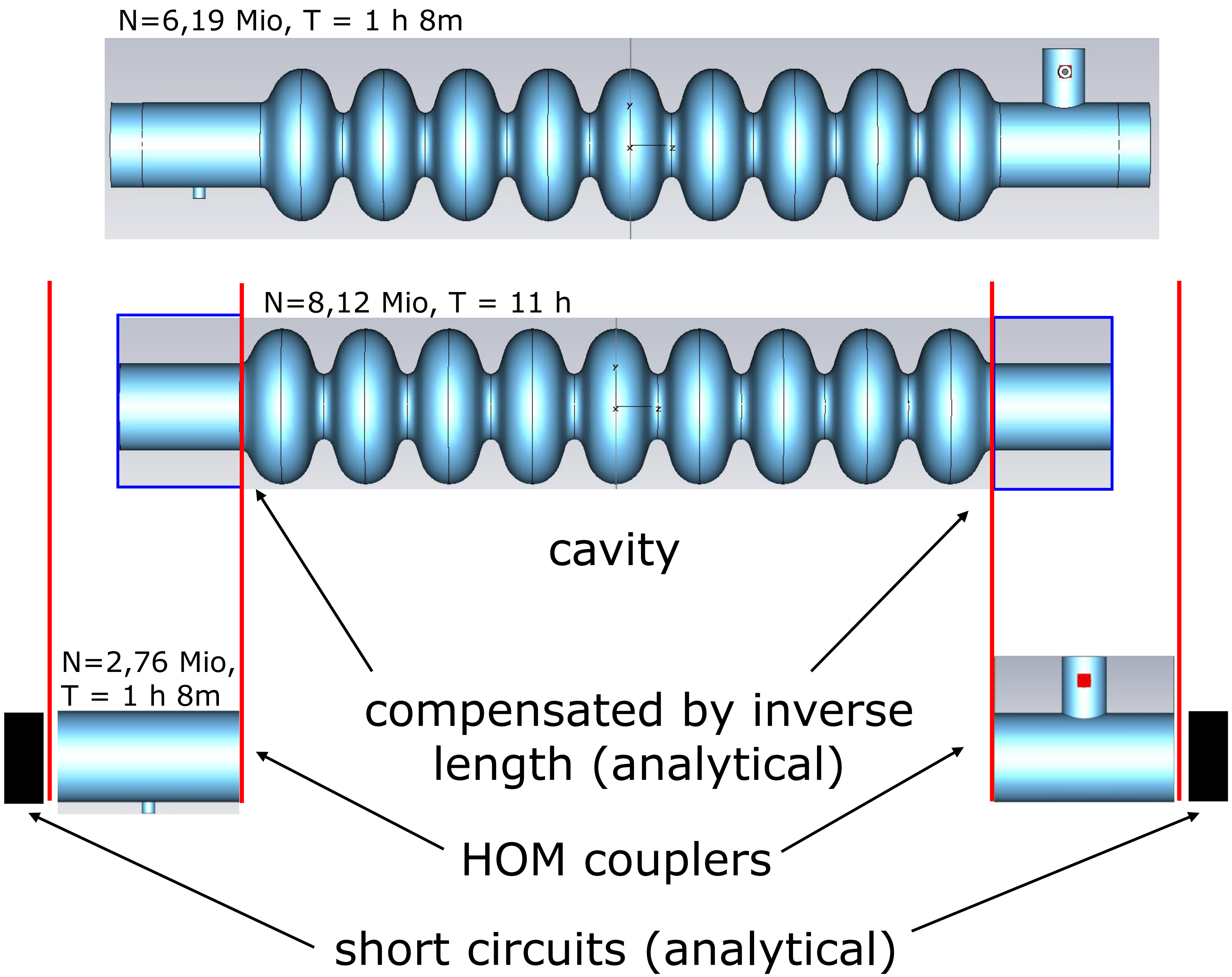




Simplifications:

- no rotation of two leg formteil.
- 90° rotation angle between HOM couplers (instead of 115°).
- no input coupler is modelled.
- PEC boundaries at the ends of the beam pipes.

Components for Coupled-S-Parameter-Calculation benchmark



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Considered modes:

1. TE11 Pol. 1
2. TE11 Pol. 2
3. TM01
4. TE21 Pol. 1
5. TE21 Pol. 2
6. TE01
7. TM11 Pol. 1
8. TM11 Pol. 2

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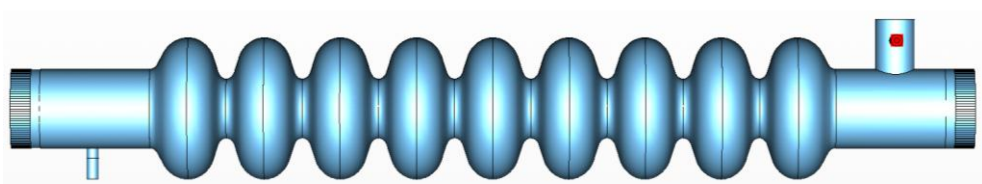
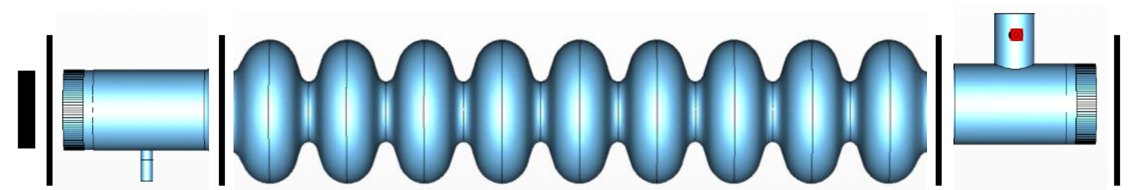
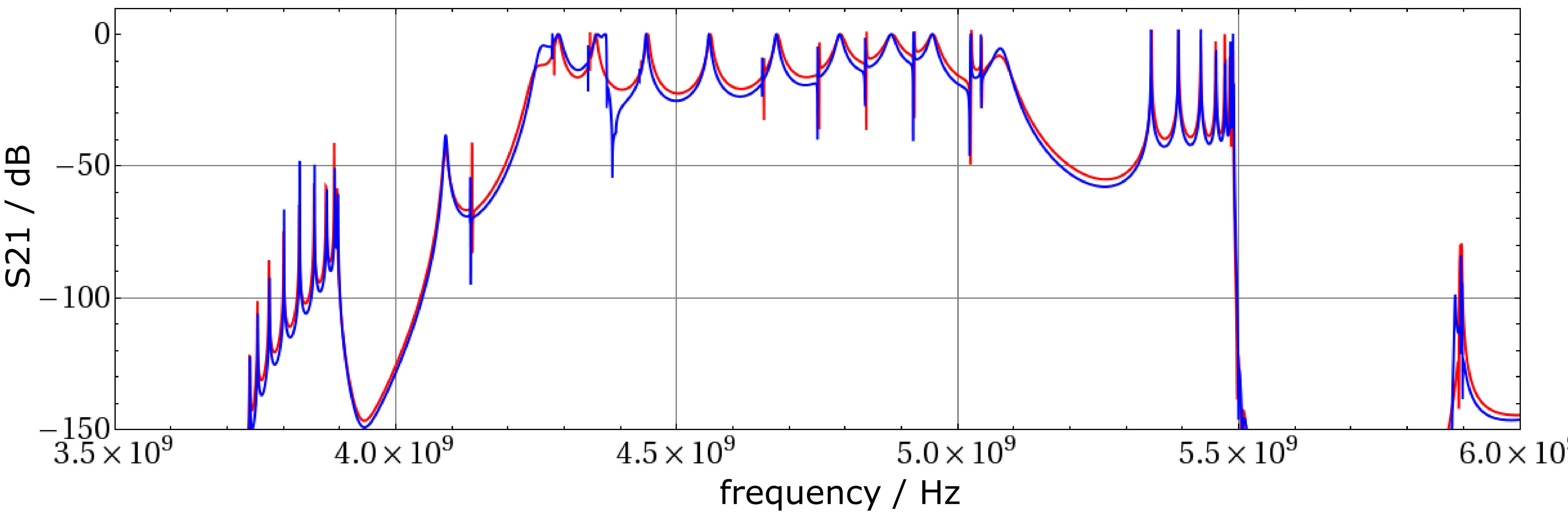
Transmisson of benchmark structure from HOM1 to HOM2

Direct computation of S-Parameters using CST‘s Fast Resonant Solver on hex. grid



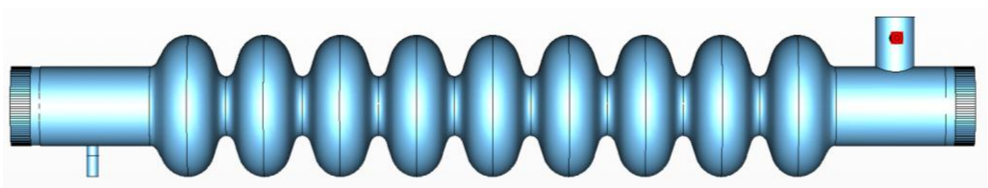
Elementwise computation of S-Parameters using CST‘s Fast Resonant Solver on hex. grid



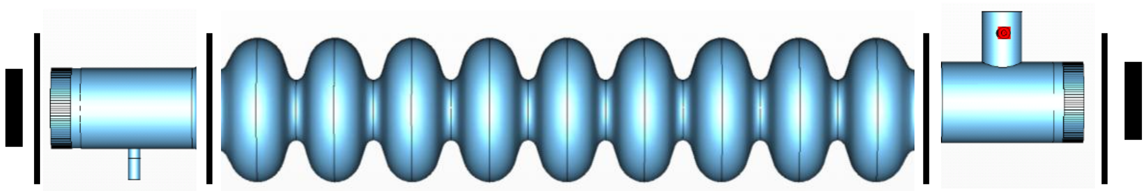


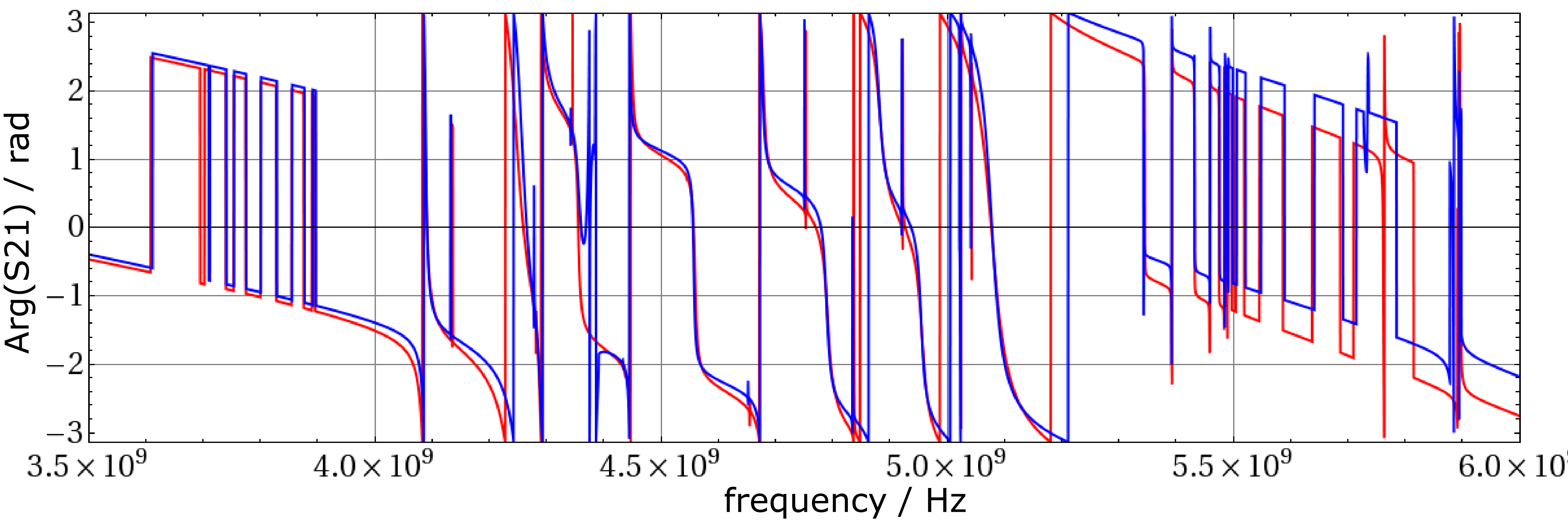
Transmisson of benchmark structure from HOM1 to HOM2

Direct computation of S-Parameters using CST's Fast Resonant Solver on hex. grid



Elementwise computation of S-Parameters using CST's Fast Resonant Solver on hex. grid





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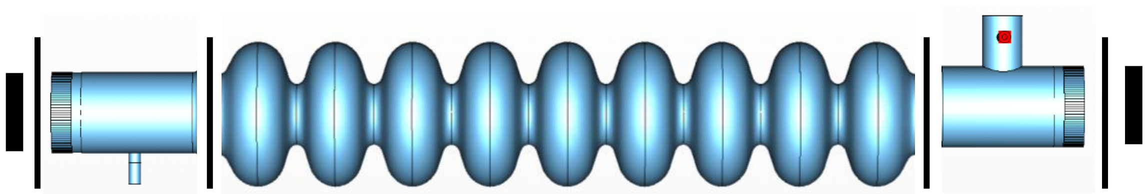
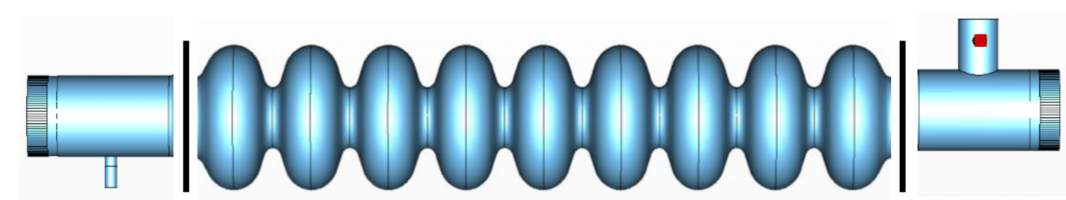
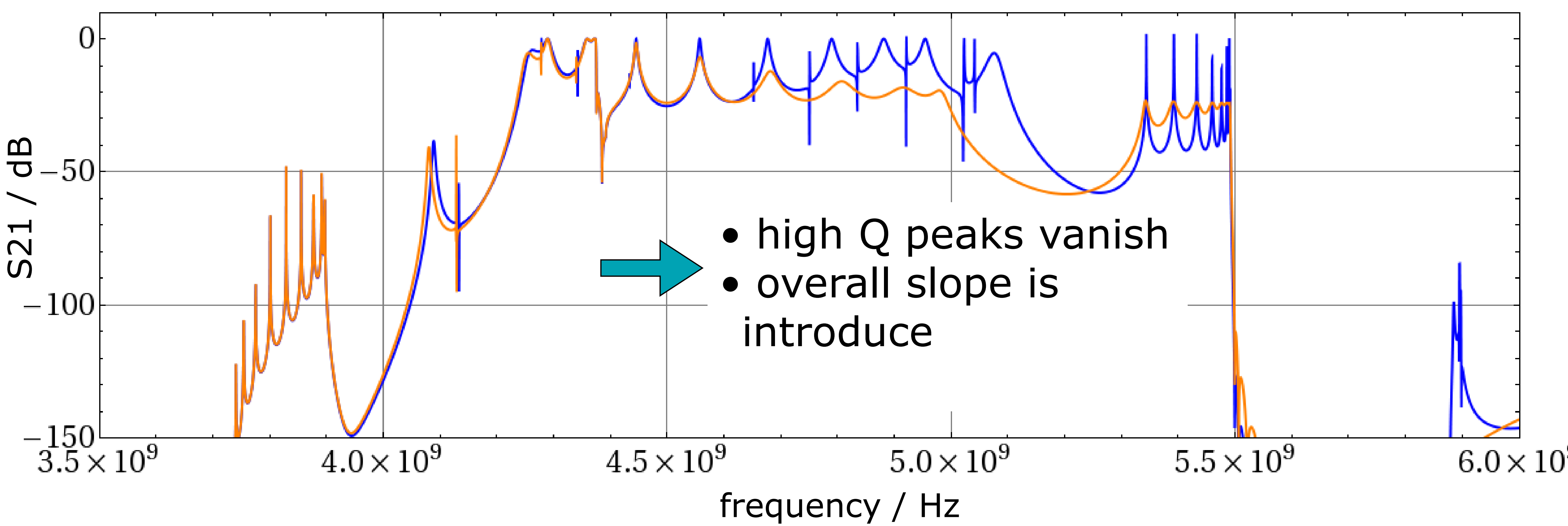
Effect of electrical shortcuts at ends of pipe on transmission from HOM1 to HOM2

Elecitrically closed beam pipes



Open beam pipes





- high Q peaks vanish
- overall slope is introduce

