Eigenmode Analysis for the PETRA III Cavity

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TECHNISCHE UNIVERSITÄT DARMSTADT

Status Report
June 24, 2016
TEMF, Darmstadt

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Motivation
- Computational Model
  - Drawings and geometry information
  - Numerical problem formulation
- Cavity tuning
  - Cell radius variation for the “reliable” and “spark” models
- Simulation results
  - Mode pattern and characteristic data for the “reliable” and “spark” models
- Summary / Outlook

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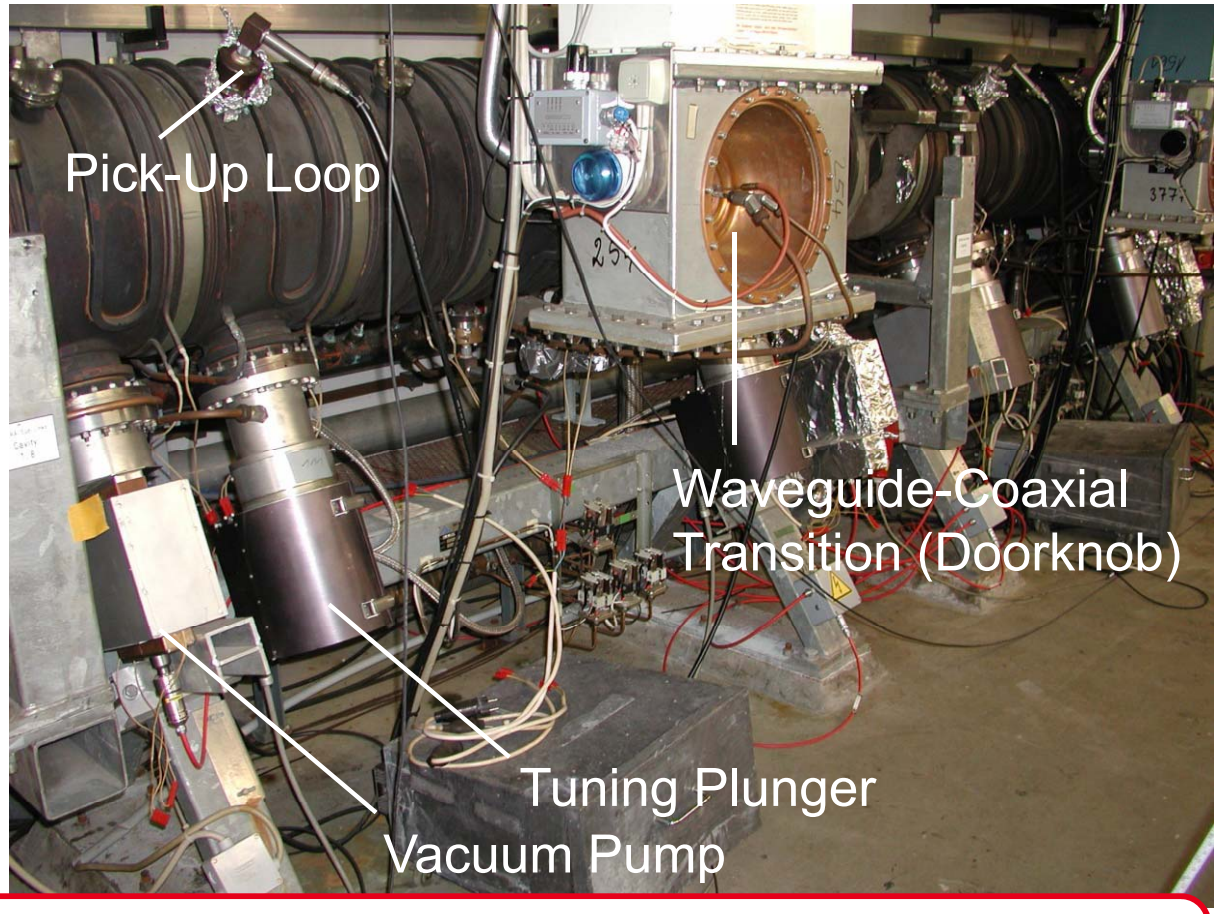
Motivation

TECHNISCHE UNIVERSITÄT DARMSTADT

- PETRA Cavities
  - Photographs



From time to time automatic switch-off of the power supply due to unexpected high fields in the cavity or waveguide system.

Motivation

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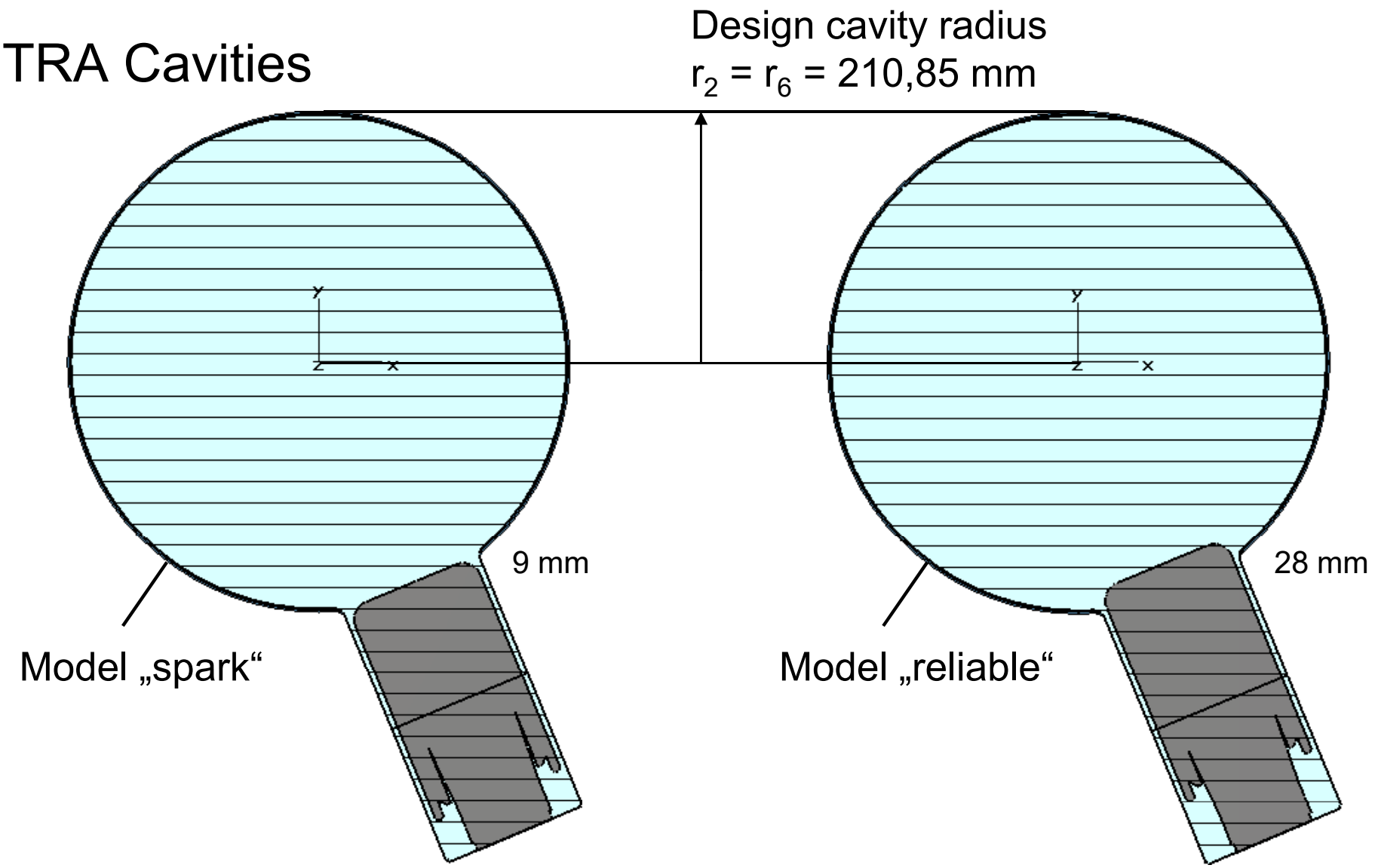
- Investigation Strategy
  - Set up model “**spark**” with plunger positions 9 mm, modify radii r_1 to r_7 such, that the fundamental mode oscillates at 499,65 MHz and the bead-pull measurement “Cavity Nr. 23” is reproduced.
  - Set up model “**reliable**” with plunger positions 28 mm, modify radii r_1 to r_7 such, that the fundamental mode oscillates at 499,65 MHz and the bead-pull measurement “Cavity Nr. 48” is reproduced.
  - Use a port boundary condition for the waveguide during the tuning procedure.

  - Calculate R/Q and Q values for all modes up to 1,2 GHz.
  - Determine max. E and max. H in the plunger slits for all nodes. Keep the energy per mode constant.
  - Use either PEC or PMC boundary conditions instead of the port boundary condition for the waveguide during the mode calculations.

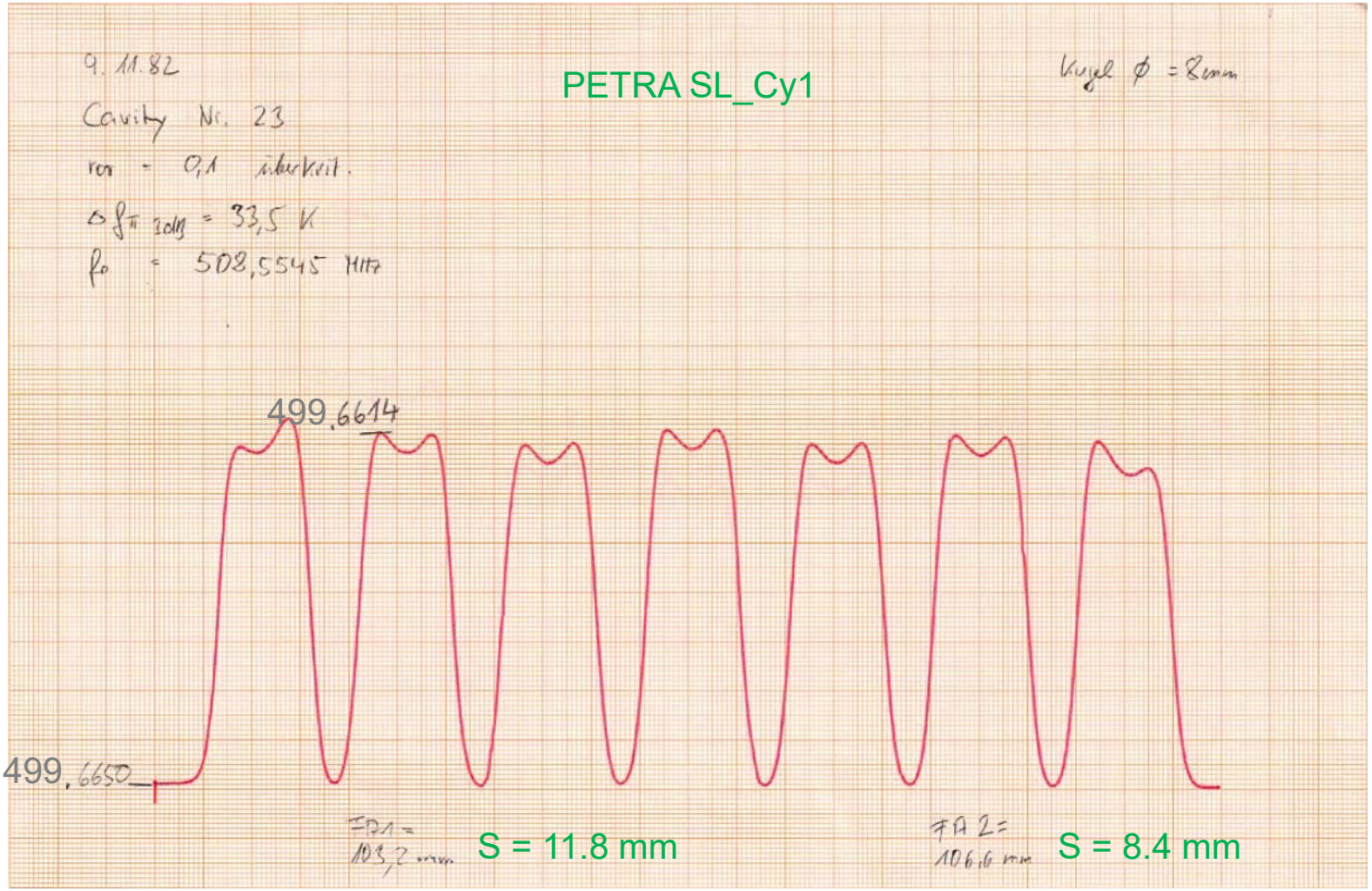
Motivation

- PETRA Cavities



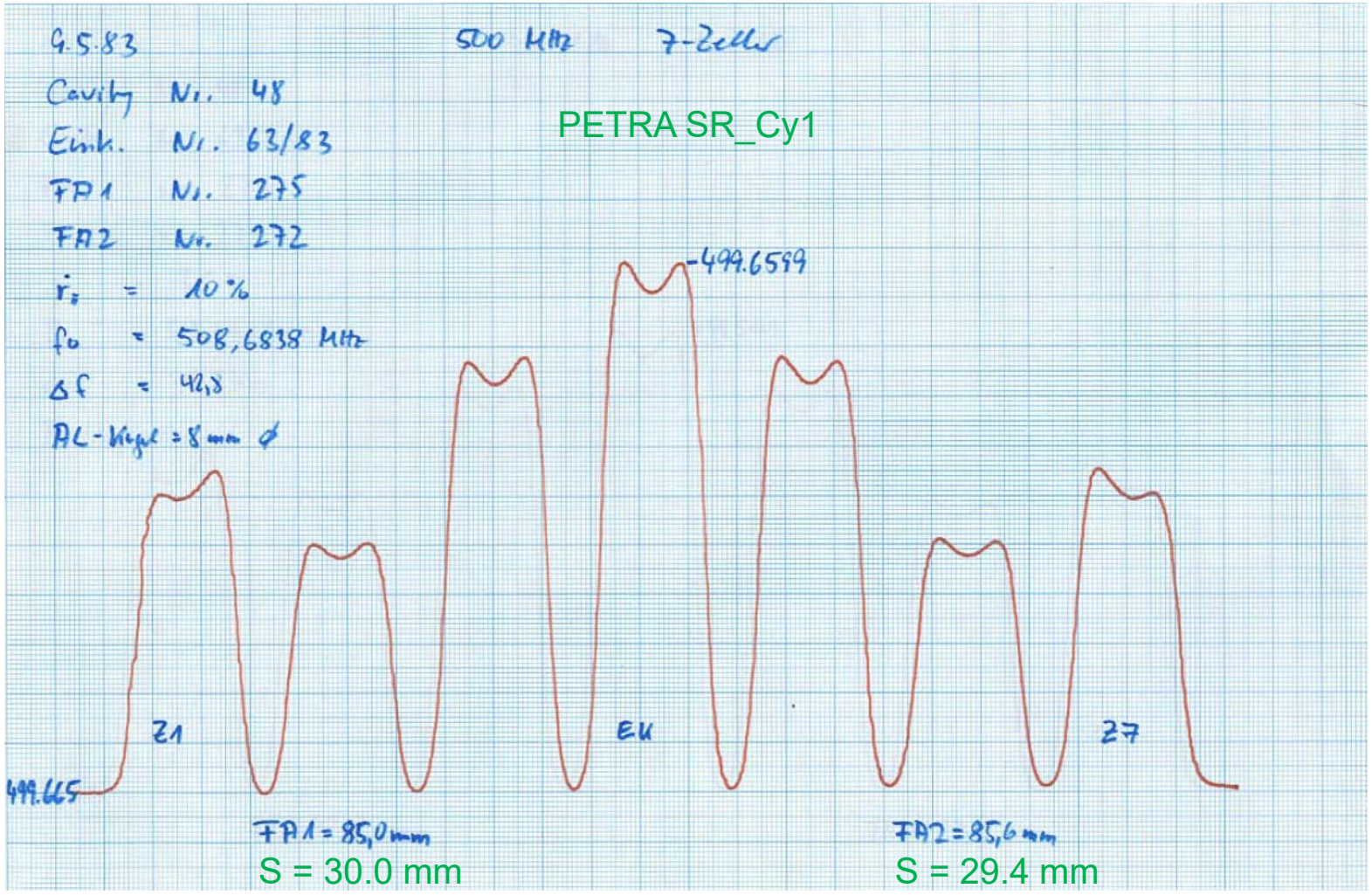
Motivation

- Bead-pulling measurement for the model “spark”



Motivation

- Bead-pulling measurement for the model “reliable”



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  - Cell radius variation for the “reliable” and “spark” models
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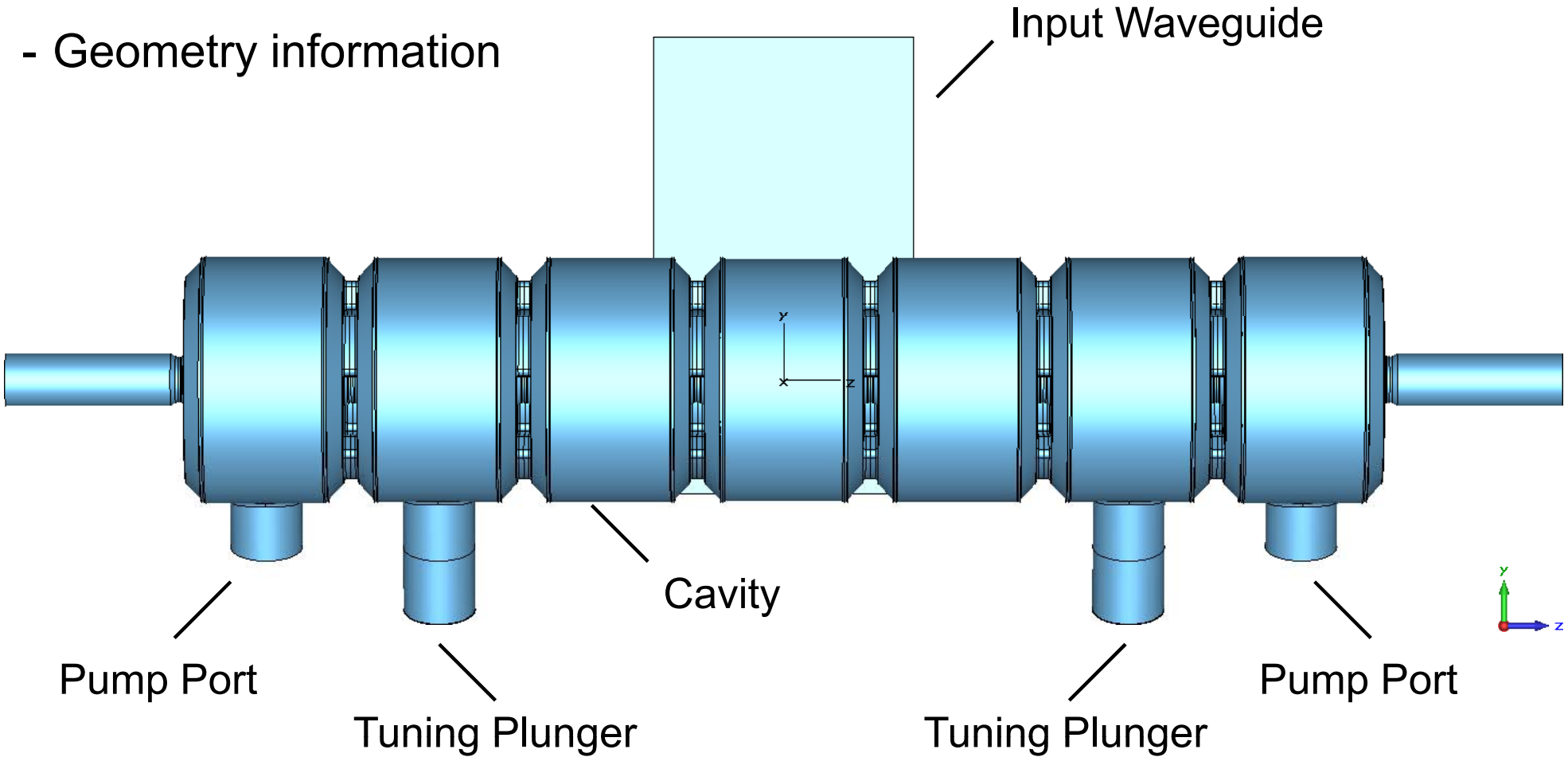
  - Mode pattern and characteristic data for the “reliable” and “spark” models
- Summary / Outlook

Computational Model

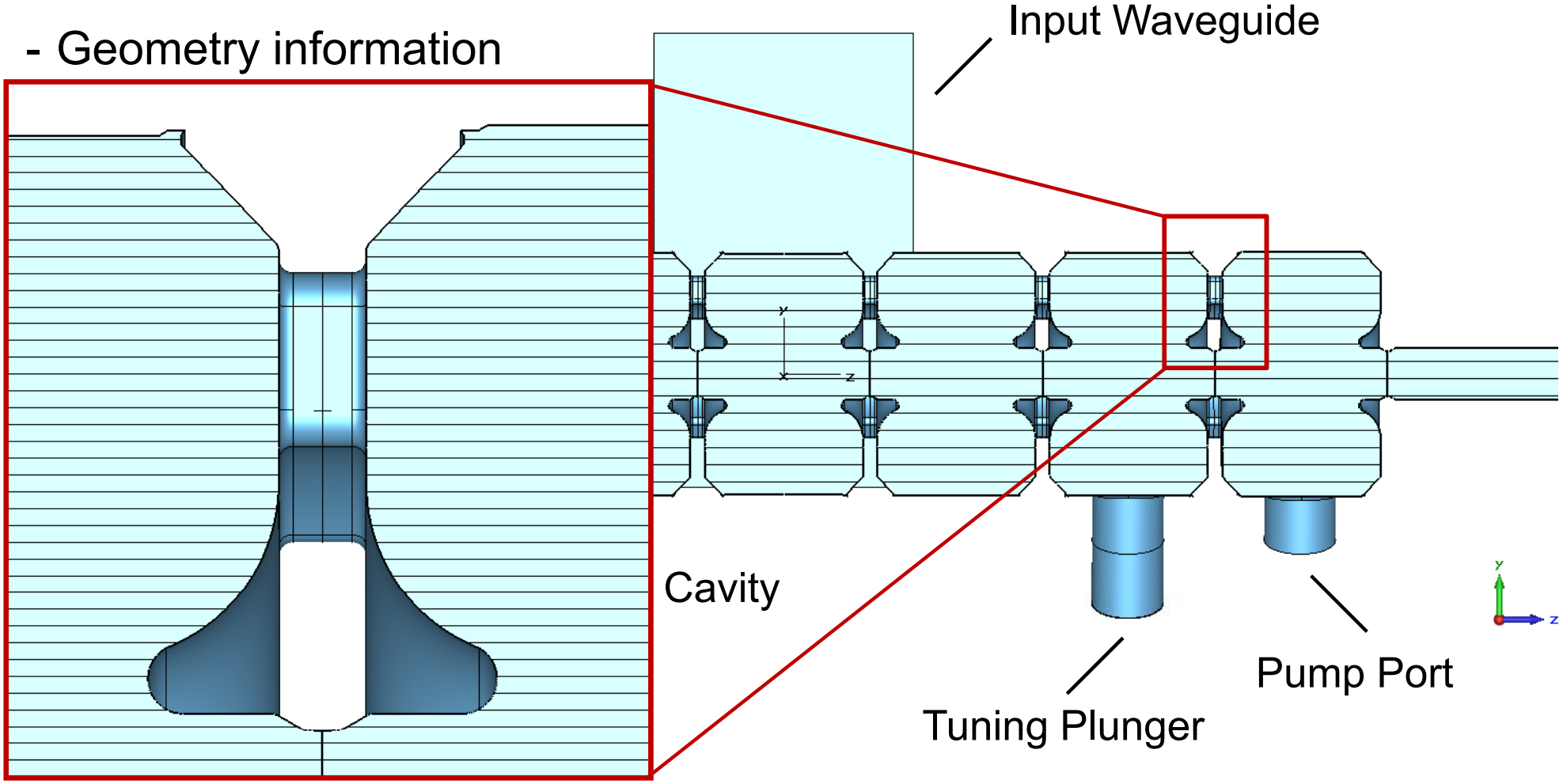
- PETRA III, 500 MHz, 7-cell Cavity
  - Geometry information



Computational Model

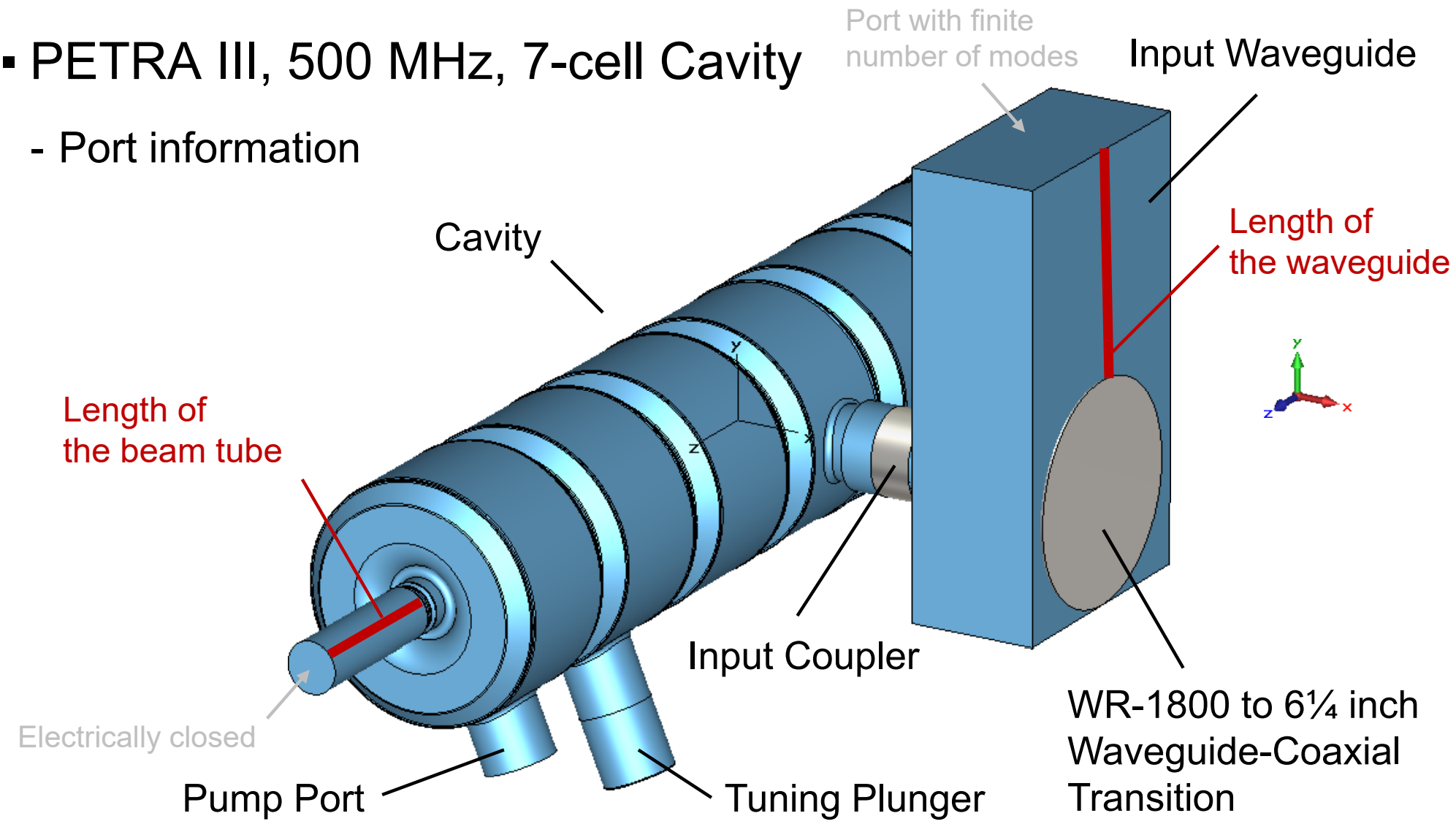
TECHNISCHE UNIVERSITÄT DARMSTADT

- PETRA III, 500 MHz, 7-cell Cavity
  - Geometry information



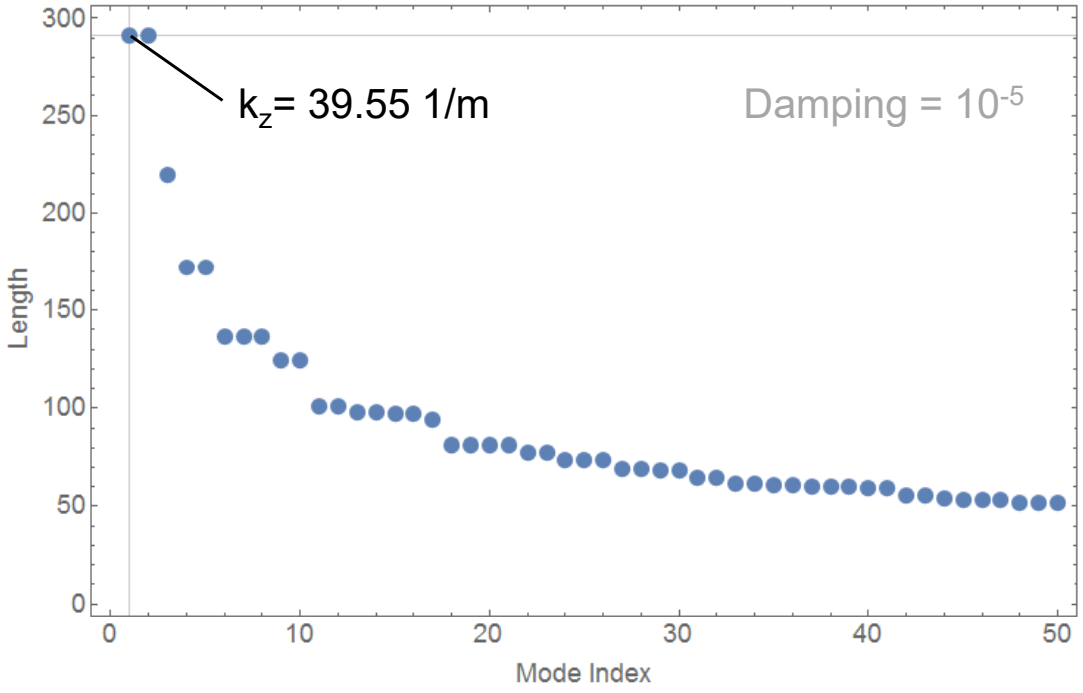
Computational Model

- PETRA III, 500 MHz, 7-cell Cavity
  - Port information



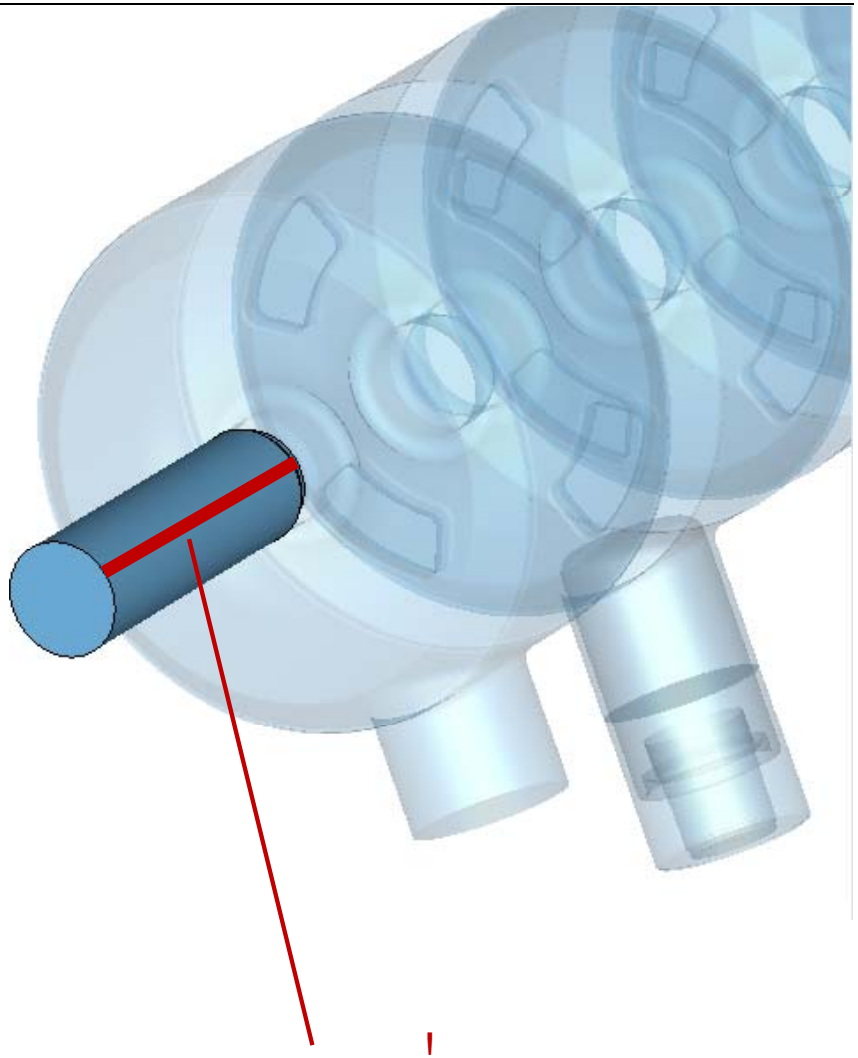
Computational Model

- PETRA III, 500 MHz, 7-cell Cavity
  - Beam-tube length



Damping 10^{-3} 10^{-4} 10^{-5} 10^{-6}

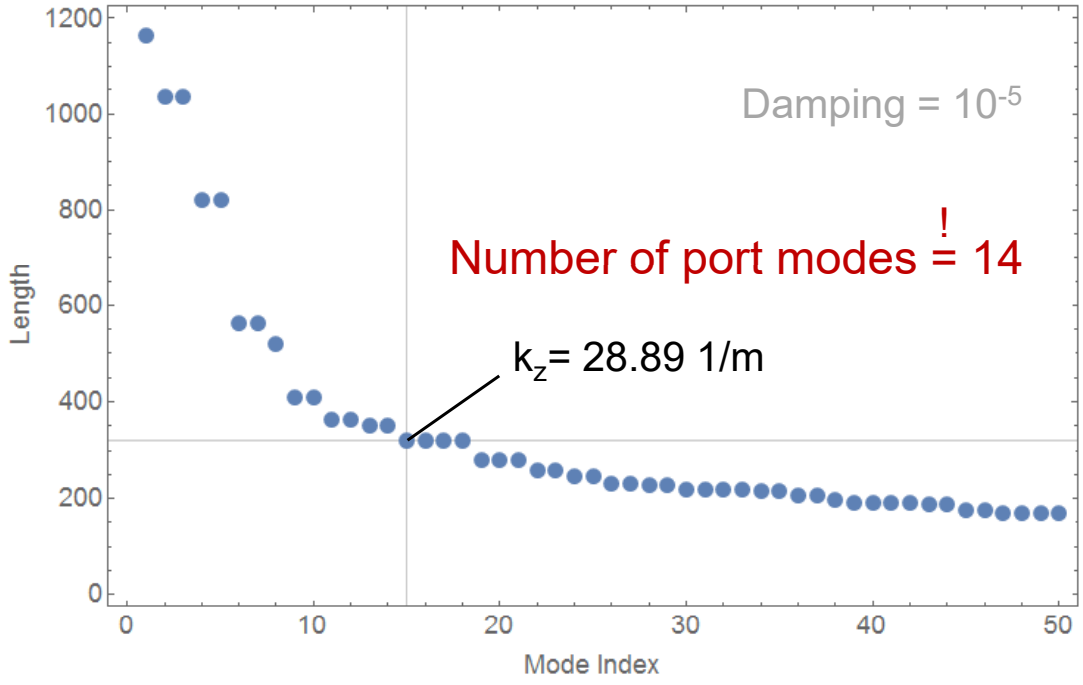
Length = { 174.6, 232.9, 291.1, 349.3 } mm



! Length = 300 mm

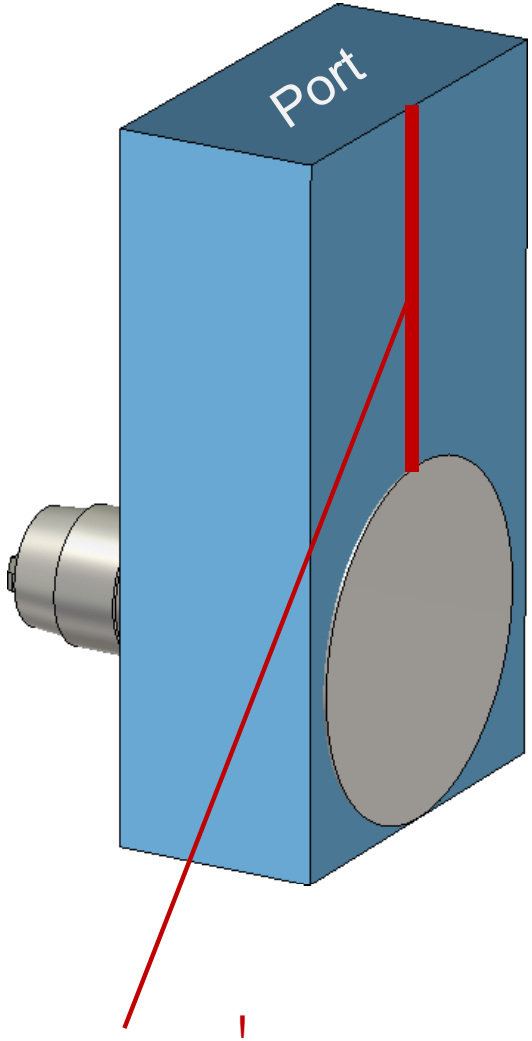
Computational Model

- PETRA III, 500 MHz, 7-cell Cavity
  - Waveguide length



Damping 10^{-3} 10^{-4} 10^{-5} 10^{-6}

Length = { 239.1, 318.8, 398.5, 478.2 } mm



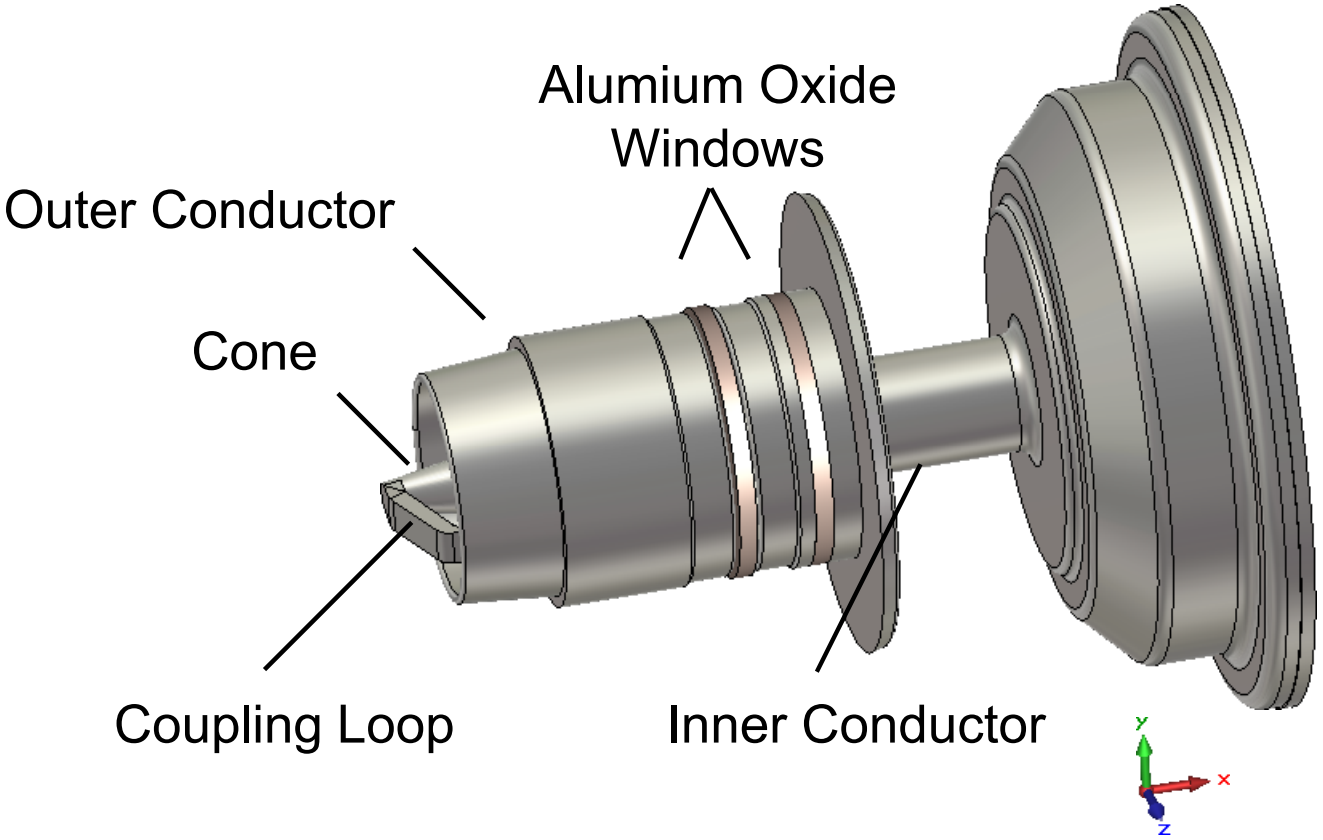
Length = 400 mm !

Computational Model

- PETRA III, 500 MHz, 7-cell Cavity
  - Geometry information (Details of the input coupler)

Photograph

http://mhf-e.desy.de/e5/e63/



Courtesy of
Kathrin Cottel

Computational Model

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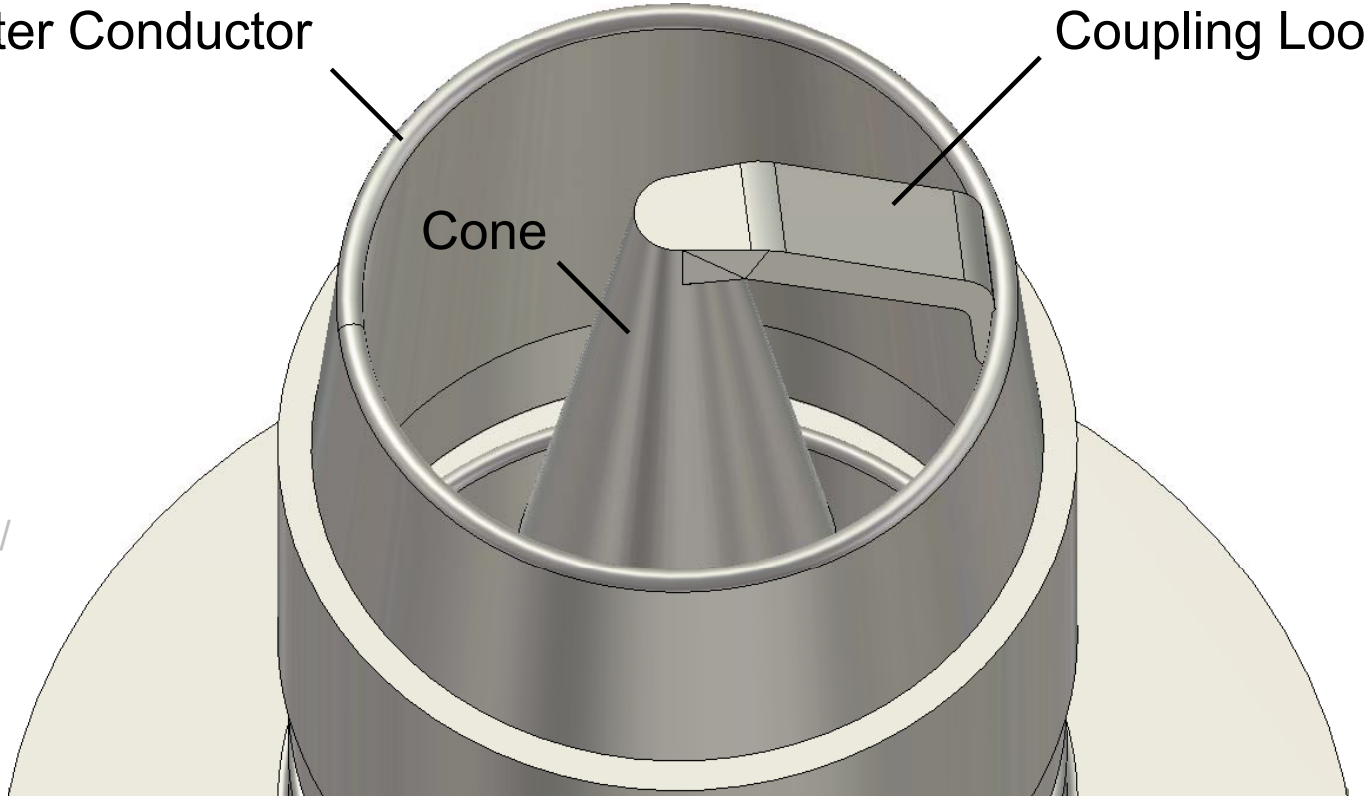

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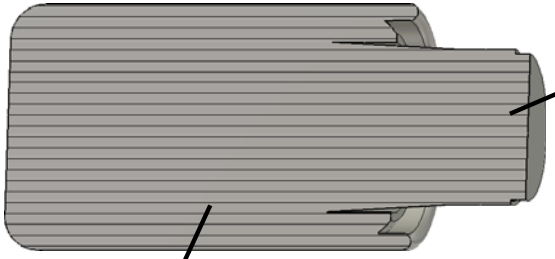
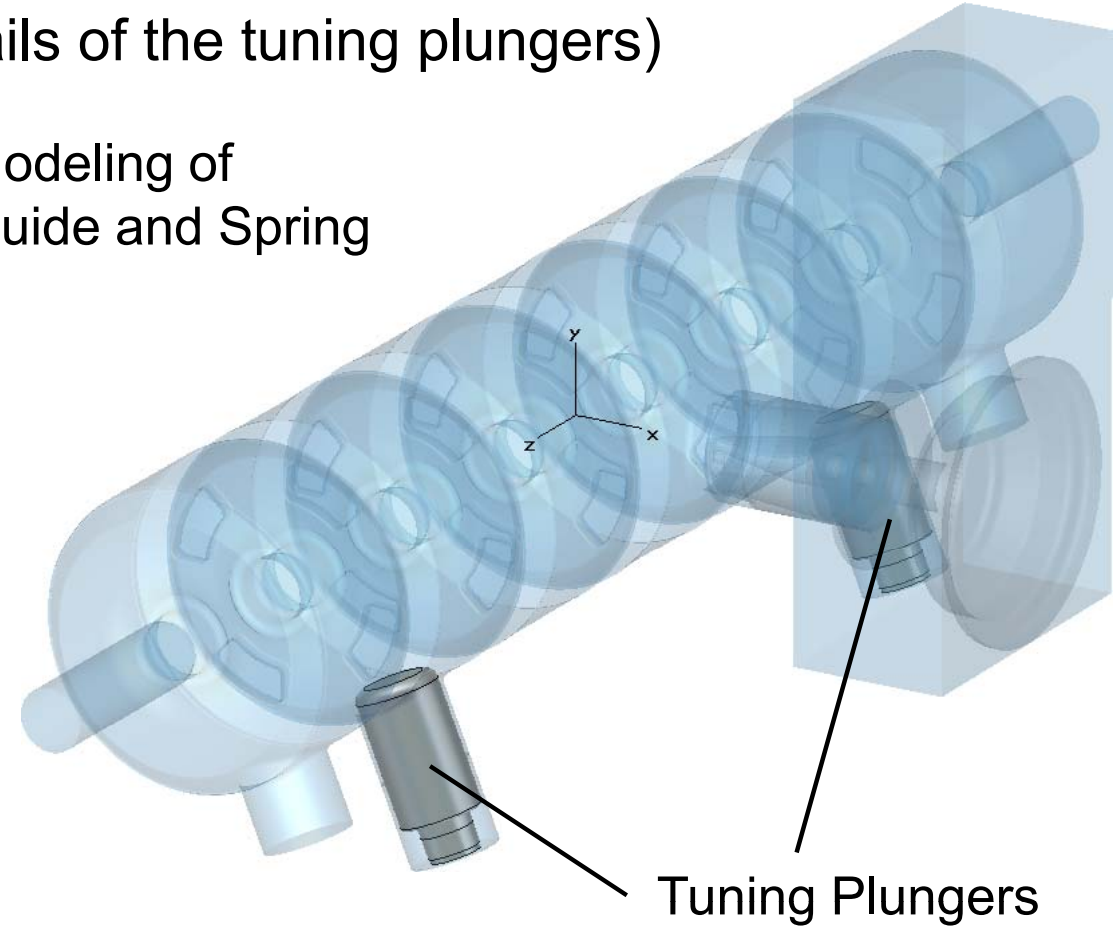
Computational Model

- PETRA III, 500 MHz, 7-cell Cavity
  - Geometry information (Details of the tuning plungers)

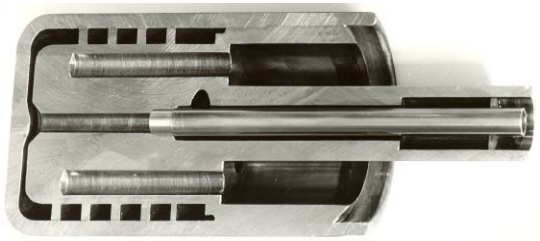


Modeling of
Guide and Spring

Neglect Cooling Channels



Photograph



http://mhf-e.desy.de/e519/e187129/

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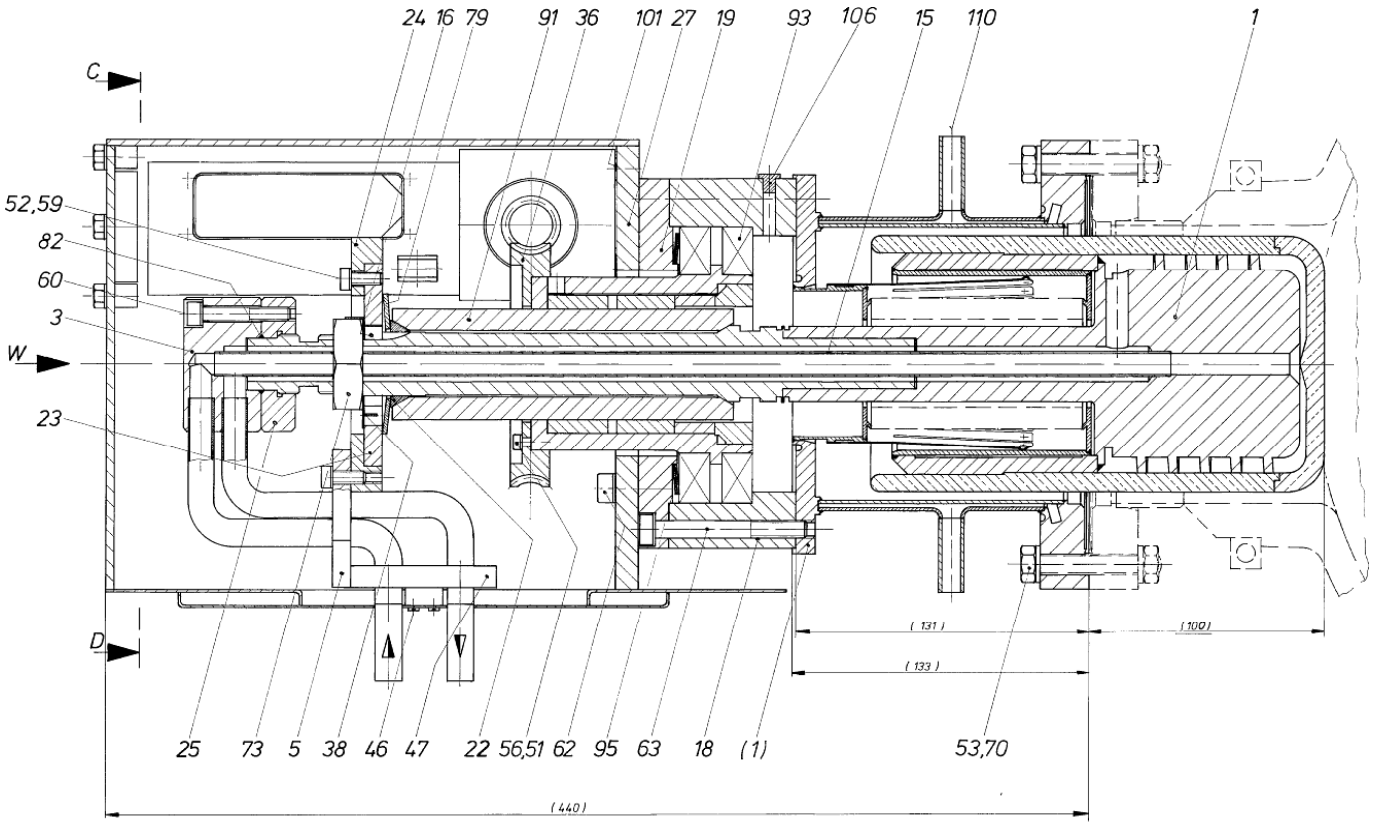

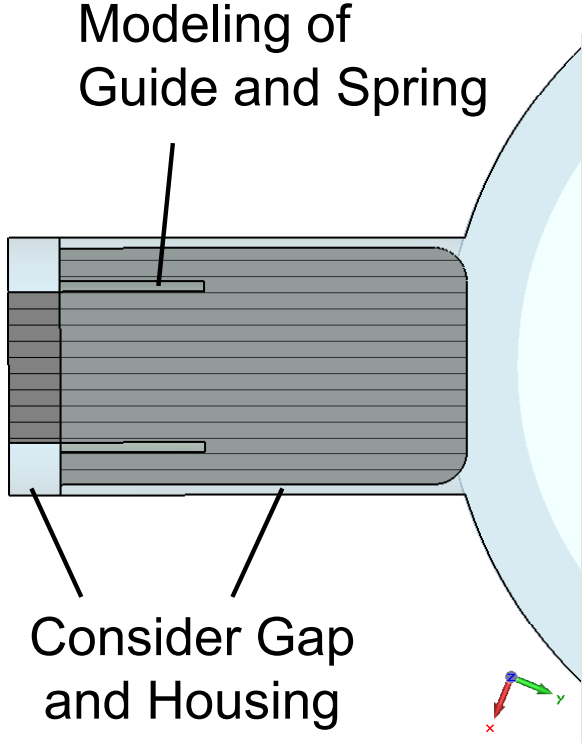

Courtesy of Michael Ebert

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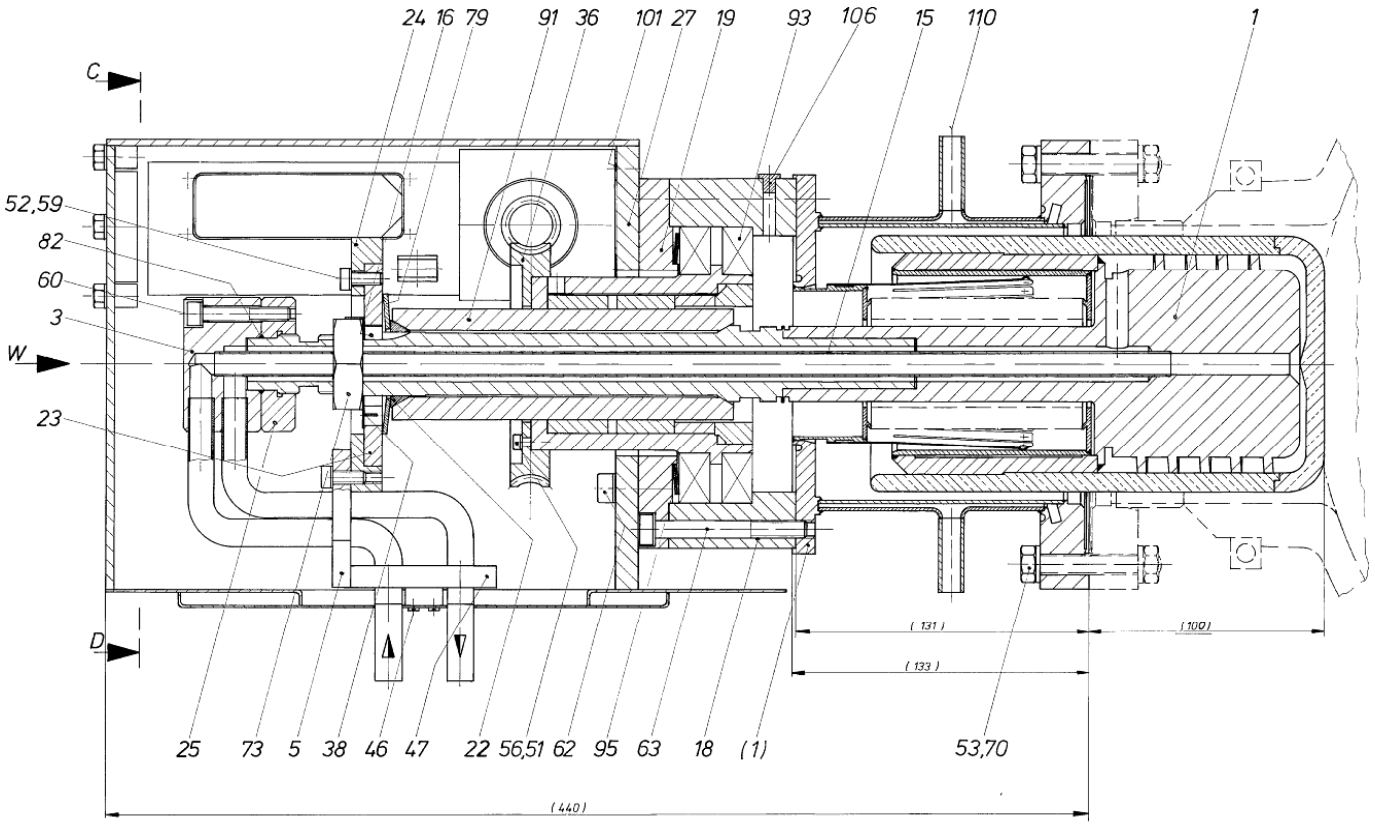

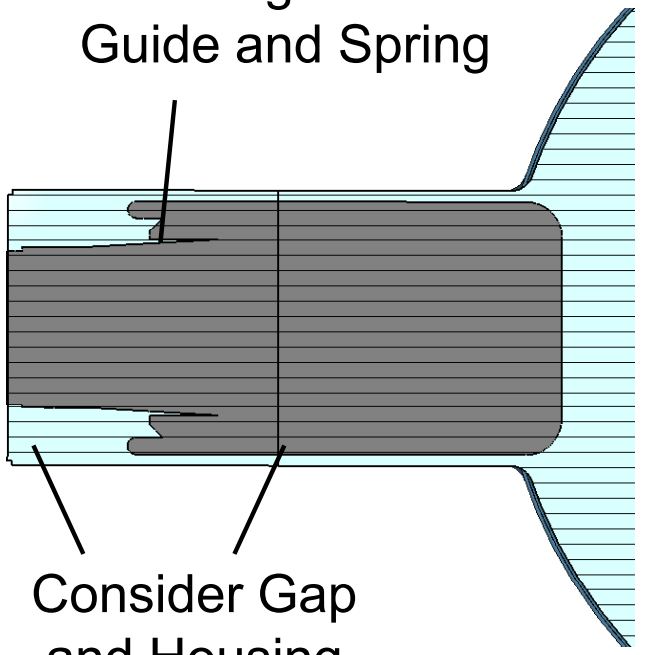

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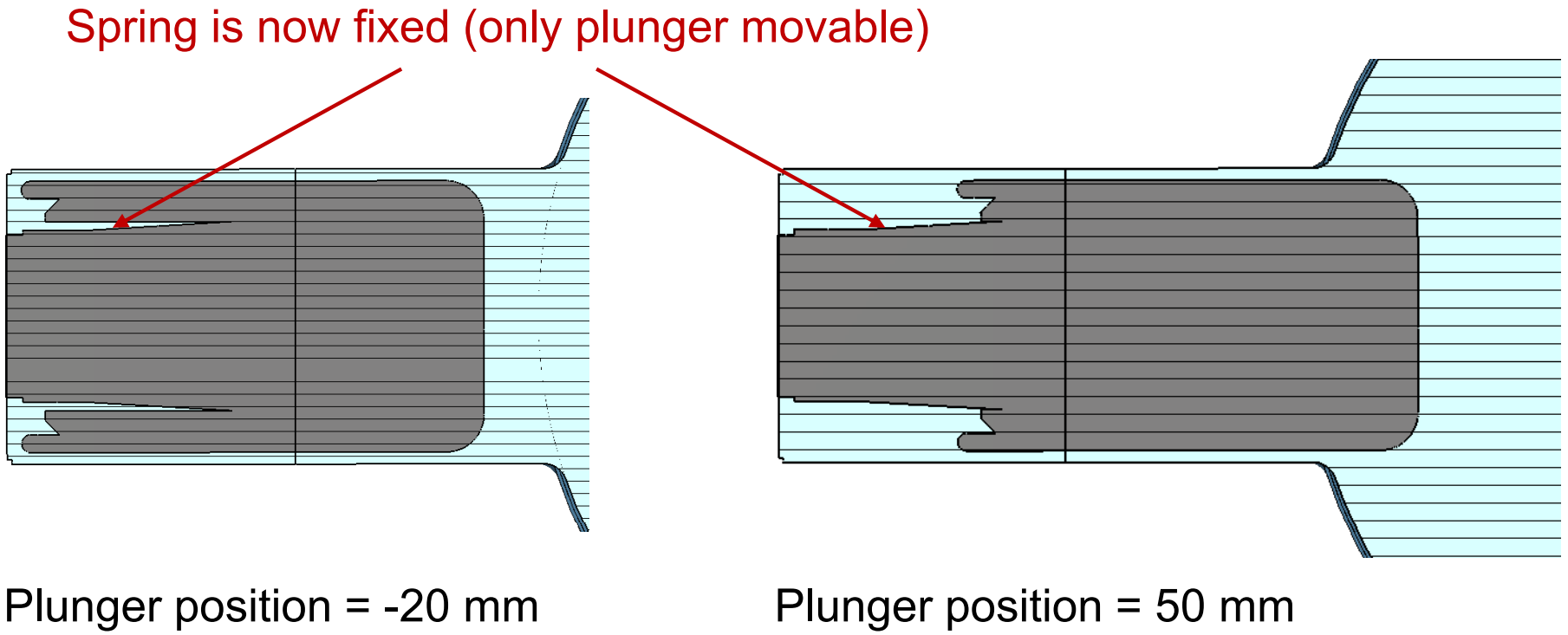

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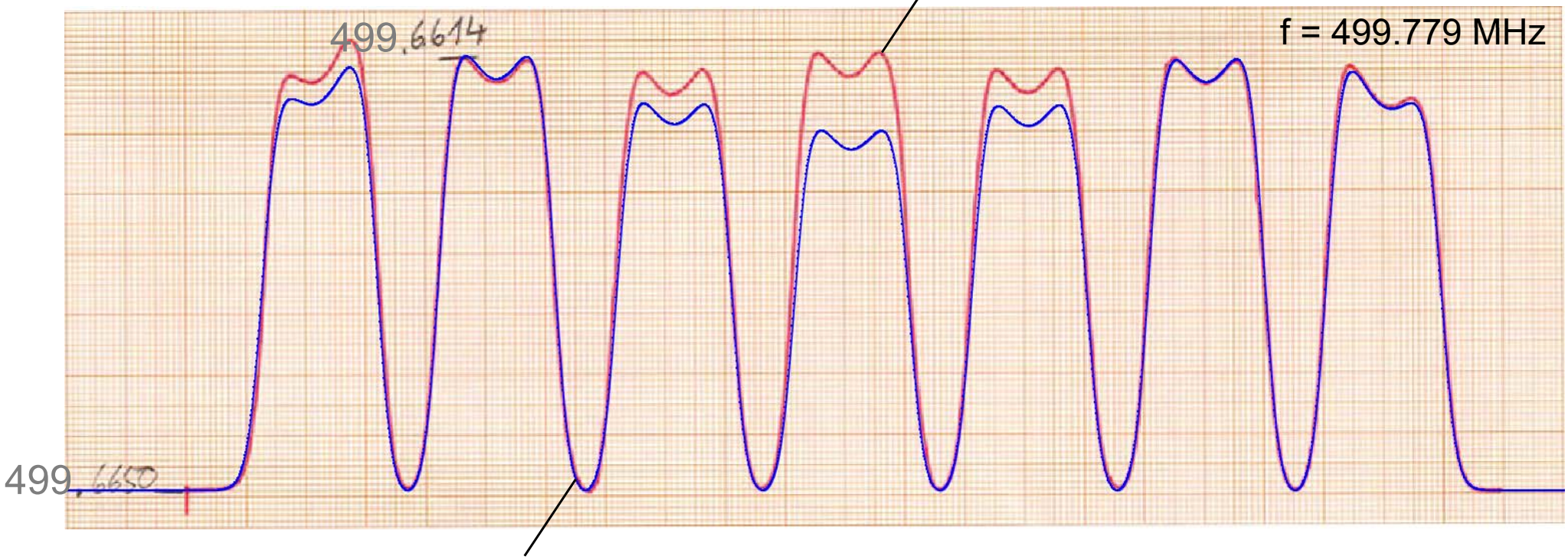
Cavity Tuning

TECHNISCHE UNIVERSITÄT DARMSTADT

- Model “spark”

Red: Bead-pulling **measurement** of the frequency shift



Blue: Bead-pulling **simulation** of the frequency shift (scaled $|\vec{E}|^2$ vs. position)

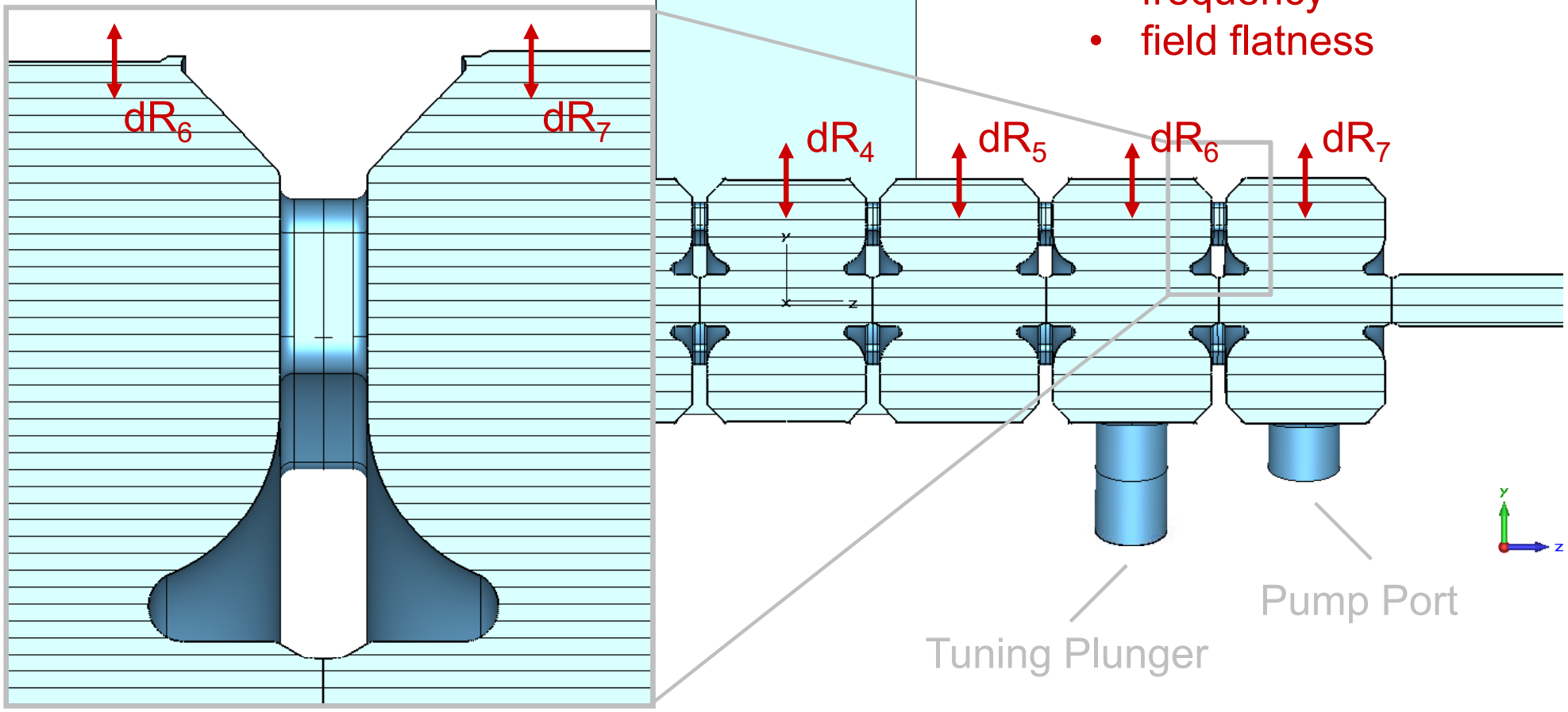
R = { 213.65, 210.85, 210.90, 209.85, 210.90, 210.85, 213.65 } mm

dR = { 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0 } mm

Cavity Tuning

TECHNISCHE UNIVERSITÄT DARMSTADT

- Model “spark”
  - Sensitivity information



Radius variation of each individual, sensitivity of:

- frequency
- field flatness

Cavity Tuning

TECHNISCHE UNIVERSITÄT DARMSTADT

- Model “spark”

	A	B	C	D	E	F	G	H	M	P	Q
1	Run ID	dR1	dR2	dR3	dR4	dR5	dR6	dR7	Tetrahedrons	Frequenz / MHz	Frequenzabweichung / kHz
2	1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1.201.788	499,778921	128,921
3	2	0,100	0,000	0,000	0,000	0,000	0,000	0,000	1.203.759		
4	3	0,000	0,100	0,000	0,000	0,000	0,000	0,000	1.203.385		
5	4	0,000	0,000	0,100	0,000	0,000	0,000	0,000	1.203.963		
6	5	0,000	0,000	0,000	0,100	0,000	0,000	0,000	1.203.160		
7	6	0,000	0,000	0,000	0,000	0,100	0,000	0,000	1.203.386		
8	7	0,000	0,000	0,000	0,000	0,000	0,100	0,000	1.203.552		
9	8	0,000	0,000	0,000	0,000	0,000	0,000	0,100	1.205.016		
10	9	0,119	-0,005	0,055	0,246	0,062	0,020	0,074	1.204.470	499,654467	4,467
11	10	0,219	-0,005	0,055	0,246	0,062	0,020	0,074	1.203.479		
12	11	0,119	0,095	0,055	0,246	0,062	0,020	0,074	1.204.842		
13	12	0,119	-0,005	0,155	0,246	0,062	0,020	0,074	1.204.895		
14	13	0,119	-0,005	0,055	0,346	0,062	0,020	0,074	1.203.122		
15	14	0,119	-0,005	0,055	0,246	0,162	0,020	0,074	1.205.044		
16	15	0,119	-0,005	0,055	0,246	0,062	0,120	0,074	1.205.204		
17	16	0,119	-0,005	0,055	0,246	0,062	0,020	0,174	1.205.856		
18	17	0,131634	-0,030270	0,067898	0,247176	0,071430	0,016050	0,086529	1.204.205	499,651077	1,077
19	18	0,232	-0,030	0,068	0,247	0,071	0,016	0,087	1.205.382		
20	19	0,132	0,070	0,068	0,247	0,071	0,016	0,087	1.204.426		
21	20	0,132	-0,030	0,168	0,247	0,071	0,016	0,087	1.203.930		
22	21	0,132	-0,030	0,068	0,347	0,071	0,016	0,087	1.205.444		
23	22	0,132	-0,030	0,068	0,247	0,171	0,016	0,087	1.204.128		
24	23	0,132	-0,030	0,068	0,247	0,071	0,116	0,087	1.204.482		
25	24	0,132	-0,030	0,068	0,247	0,071	0,016	0,187	1.204.001		
26	25	0,133614	-0,031288	0,068746	0,246354	0,075181	0,013435	0,088617	1.203.513	499,649611	-0,389
27											

Cavity Tuning

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- Model “spark”

Red: Bead-pulling **measurement** of the frequency shift

Blue: Bead-pulling **simulation** of the frequency shift (scaled $|\vec{E}|^2$ vs. position)

R = { 213.65, 210.85, 210.90, 209.85, 210.90, 210.85, 213.65 } mm

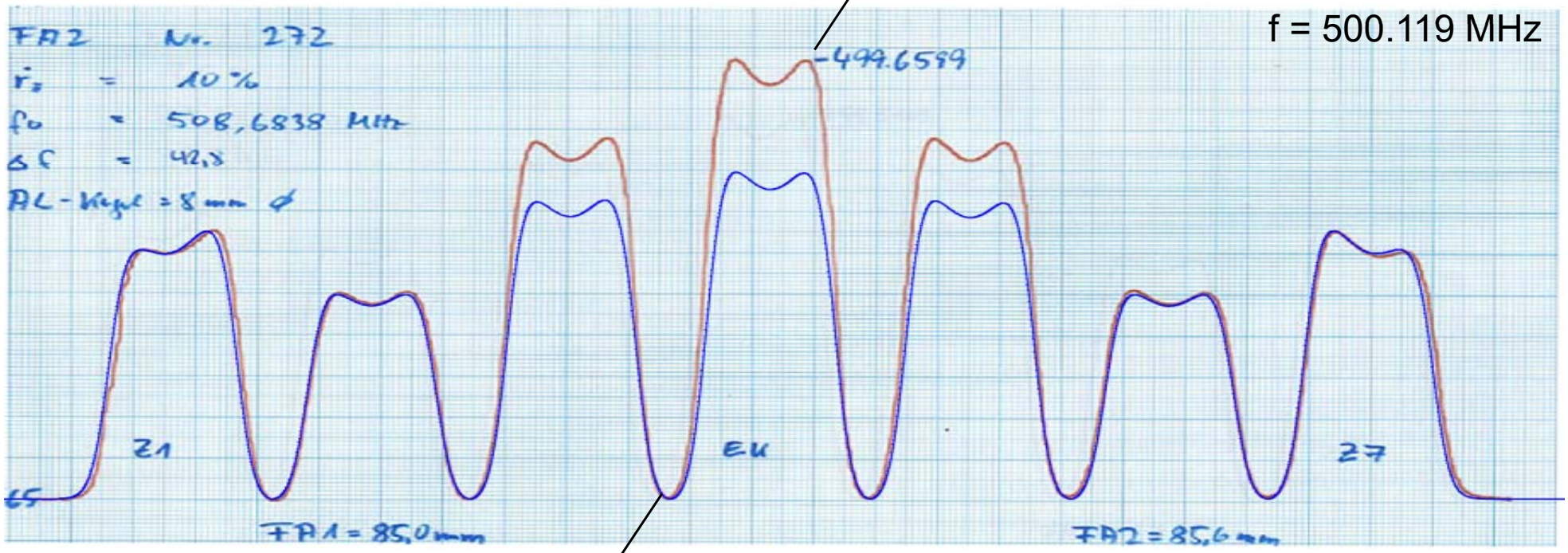
dR = { 0.134, -0.031, 0.069, 0.246, 0.075, 0.013, 0.087 } mm

Cavity Tuning

TECHNISCHE UNIVERSITÄT DARMSTADT

- Model “reliable”

Red: Bead-pulling **measurement** of the frequency shift



Blue: Bead-pulling **simulation** of the frequency shift (scaled $|\vec{E}|^2$ vs. position)

R = { 213.65, 210.85, 210.90, 209.85, 210.90, 210.85, 213.65 } mm

dR = { 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0 } mm

Cavity Tuning

TECHNISCHE UNIVERSITÄT DARMSTADT

- Model “reliable”

	A	B	C	D	E	F	G	H	P	Q
1	Run ID	dR1	dR2	dR3	dR4	dR5	dR6	dR7	Frequenz / MHz	Frequenzabweichung / kHz
2	1	0,000	0,000	0,000	0,000	0,000	0,000	0,000	500,119049	469,049
3	2	0,100	0,000	0,000	0,000	0,000	0,000	0,000		
4	3	0,000	0,100	0,000	0,000	0,000	0,000	0,000		
5	4	0,000	0,000	0,100	0,000	0,000	0,000	0,000		
6	5	0,000	0,000	0,000	0,100	0,000	0,000	0,000		
7	6	0,000	0,000	0,000	0,000	0,100	0,000	0,000		
8	7	0,000	0,000	0,000	0,000	0,000	0,100	0,000		
9	8	0,000	0,000	0,000	0,000	0,000	0,000	0,100		
10	9	0,216	0,163	0,324	0,451	0,285	0,162	0,272	499,676489	26,489
11	10	0,316	0,163	0,324	0,451	0,285	0,162	0,272		
12	11	0,216	0,263	0,324	0,451	0,285	0,162	0,272		
13	12	0,216	0,163	0,424	0,451	0,285	0,162	0,272		
14	13	0,216	0,163	0,324	0,551	0,285	0,162	0,272		
15	14	0,216	0,163	0,324	0,451	0,385	0,162	0,272		
16	15	0,216	0,163	0,324	0,451	0,285	0,262	0,272		
17	16	0,216	0,163	0,324	0,451	0,285	0,162	0,372		
18	17	0,292	0,143	0,320	0,460	0,317	0,156	0,289	499,653842	3,842
19	18	0,392	0,143	0,320	0,460	0,317	0,156	0,289		
20	19	0,292	0,243	0,320	0,460	0,317	0,156	0,289		
21	20	0,292	0,143	0,420	0,460	0,317	0,156	0,289		
22	21	0,292	0,143	0,320	0,560	0,317	0,156	0,289		
23	22	0,292	0,143	0,320	0,460	0,417	0,156	0,289		
24	23	0,292	0,143	0,320	0,460	0,317	0,256	0,289		
25	24	0,292	0,143	0,320	0,460	0,317	0,156	0,389		
26	25	0,295	0,147	0,320	0,462	0,322	0,152	0,292	499,649023	-0,977
27	26	0,295461	0,147189	0,320166	0,462386	0,321769	0,152284	0,292034	499,650115	0,115
28										

Cavity Tuning

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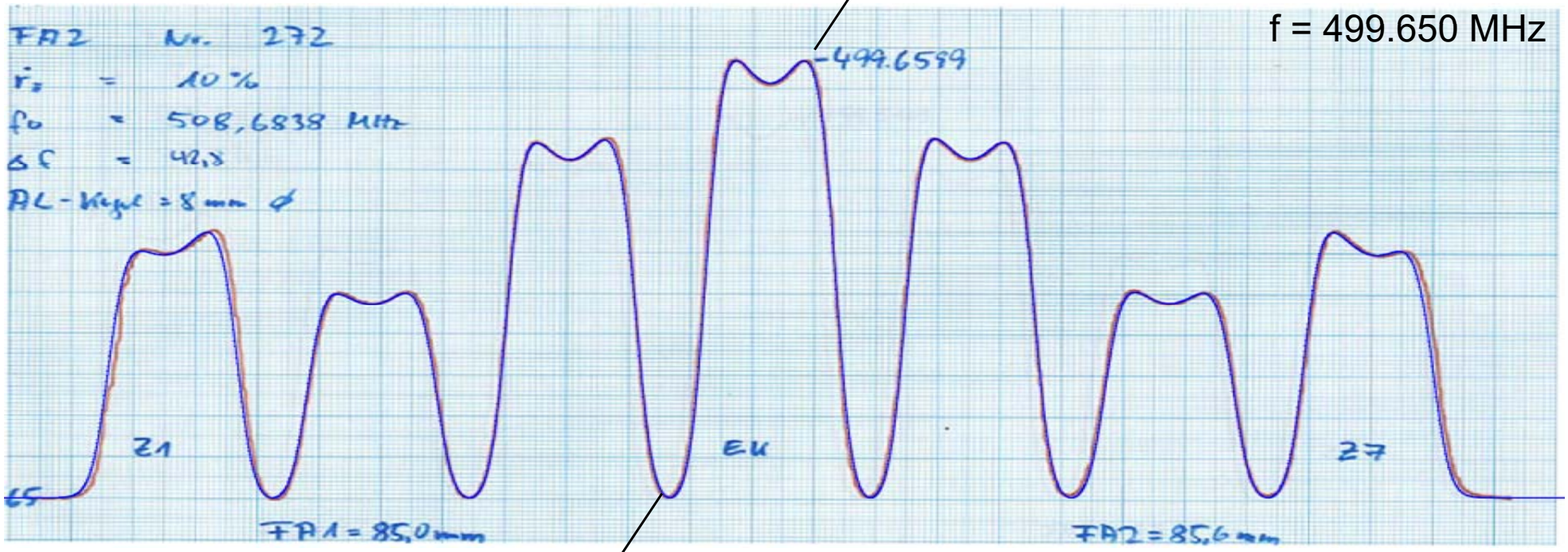
- Model “reliable”

Red: Bead-pulling **measurement** of the frequency shift



Blue: Bead-pulling **simulation** of the frequency shift (scaled $|\vec{E}|^2$ vs. position)

R = { 213.65, 210.85, 210.90, 209.85, 210.90, 210.85, 213.65 } mm

dR = { 0.295, 0.147, 0.320, 0.462, 0.322, 0.152, 0.292 } mm

Cavity Tuning

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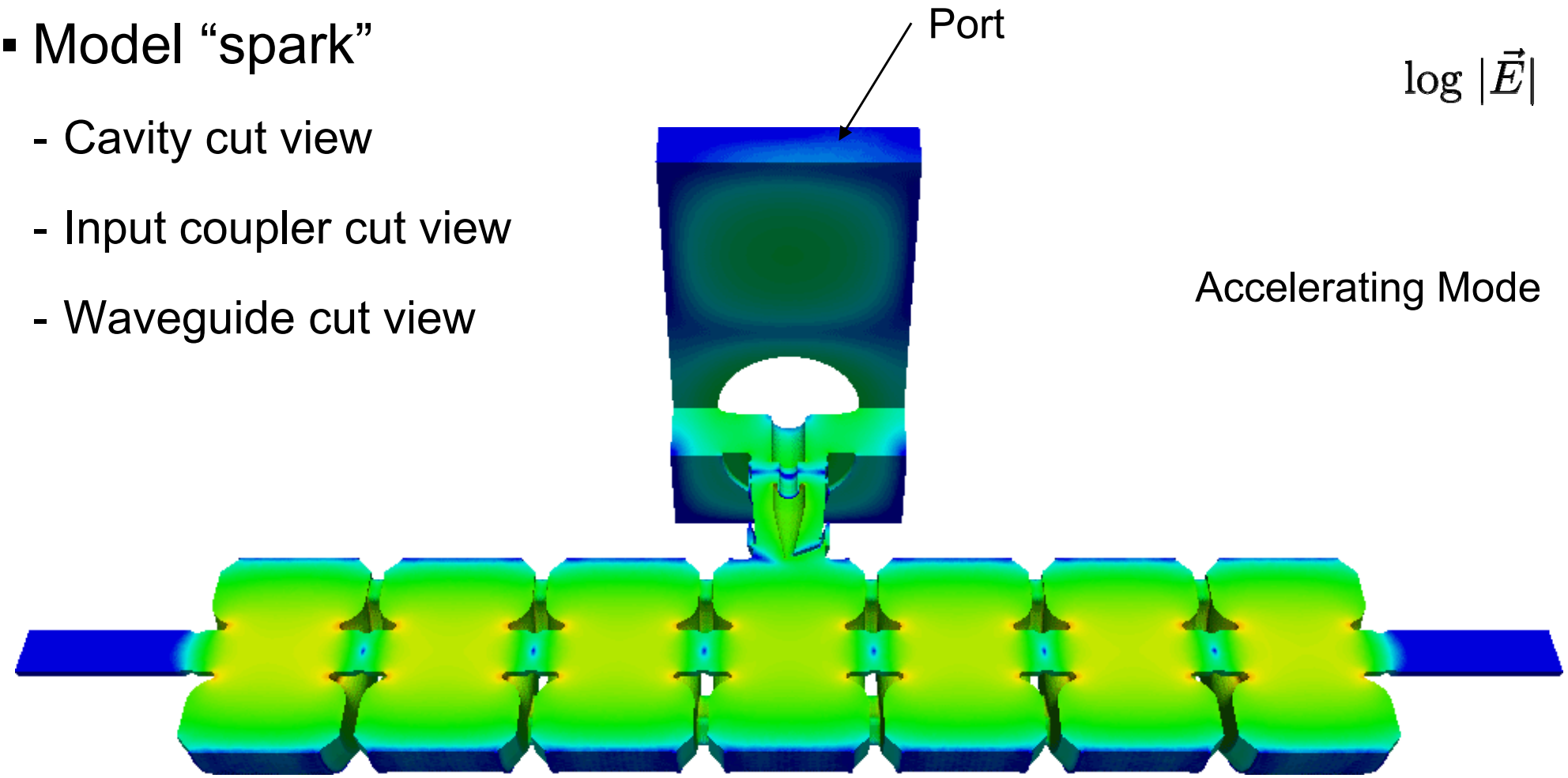
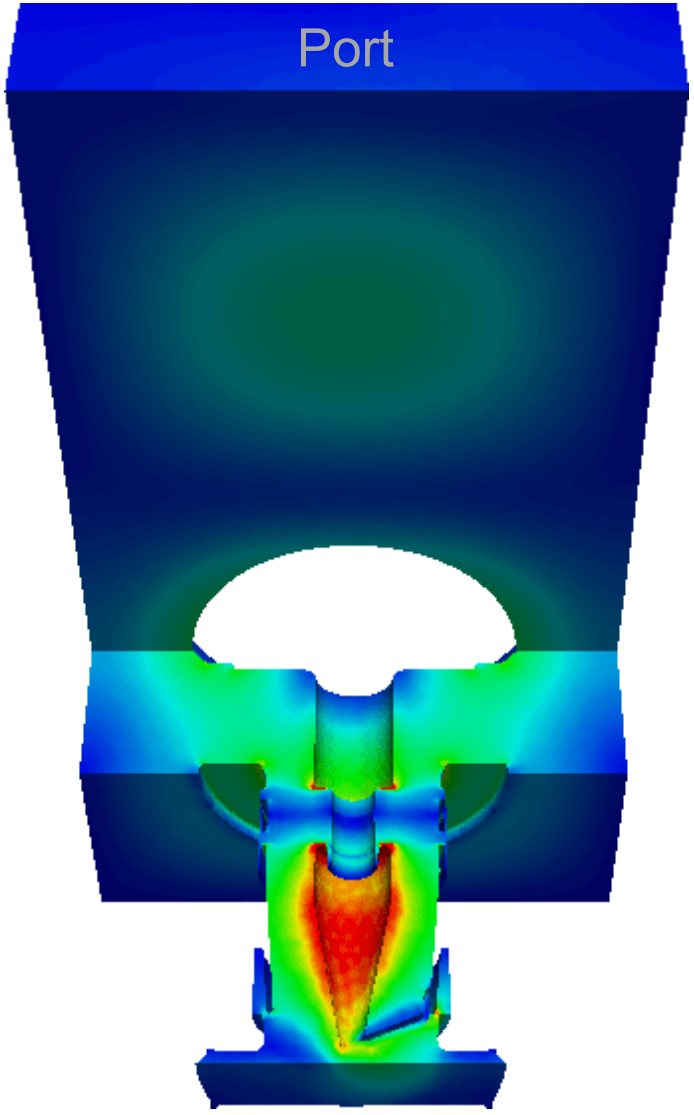
- Model “spark”
  - Cavity cut view
  - Input coupler cut view
  - Waveguide cut view



Cavity Tuning

TECHNISCHE UNIVERSITÄT DARMSTADT

- Model “spark”
  - Cavity truncated
  - Input coupler cut view
  - Waveguide cut view



Accelerating Mode

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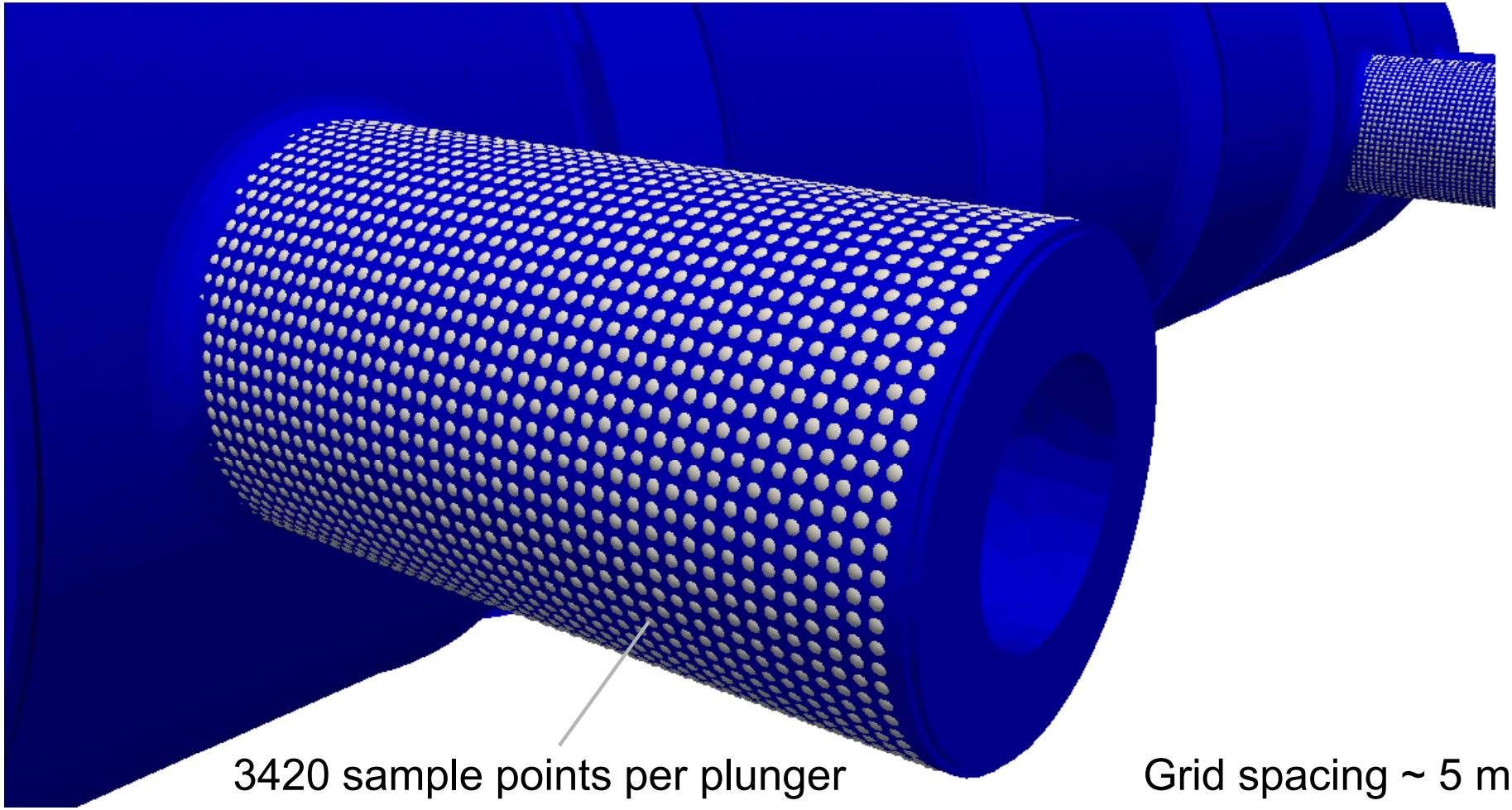
Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

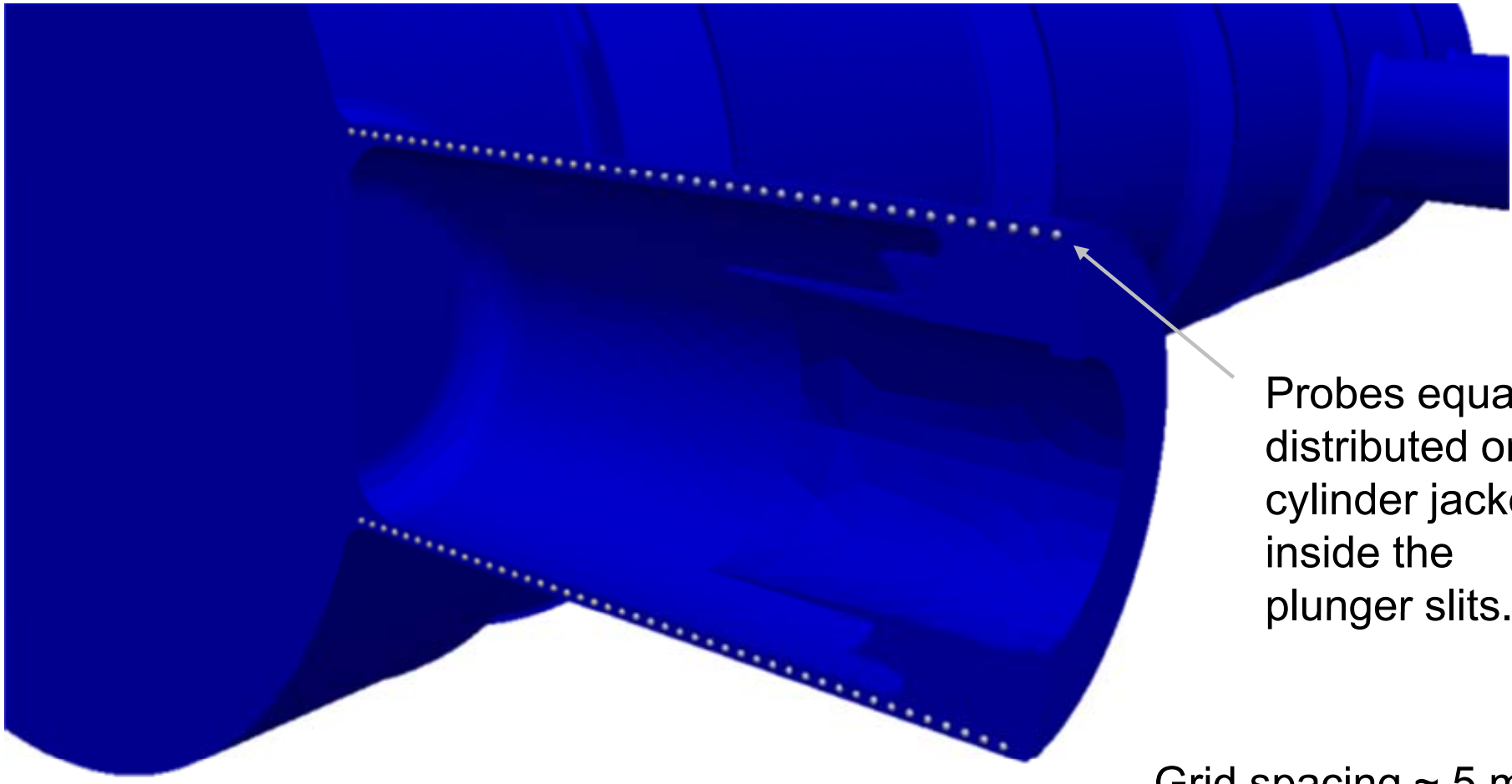
- Probe Locations for Maximum Field Determination



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

- Probe Locations for Maximum Field Determination



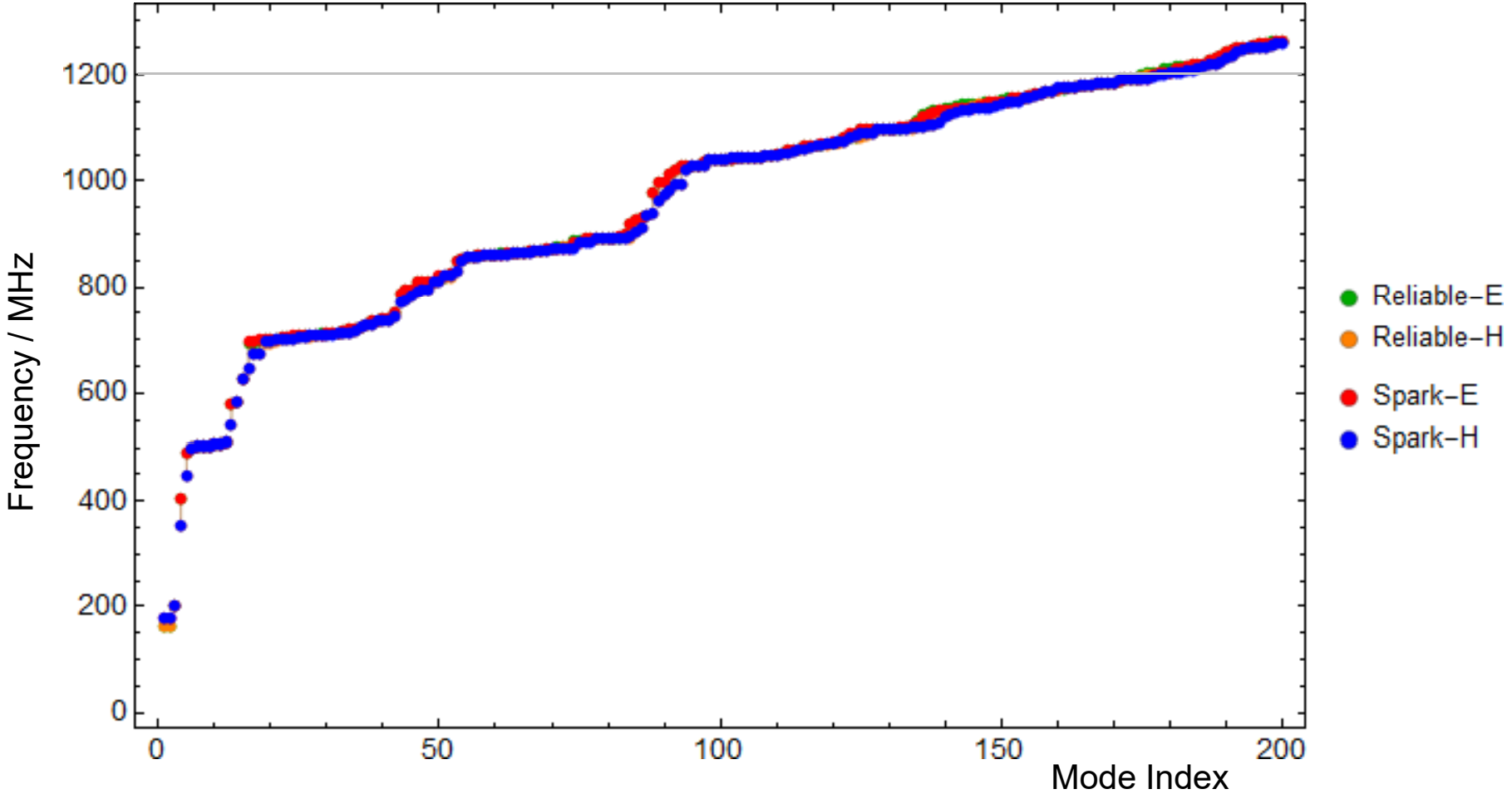
Probes equally distributed on a cylinder jacket inside the plunger slits.

Grid spacing ~ 5 mm

Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

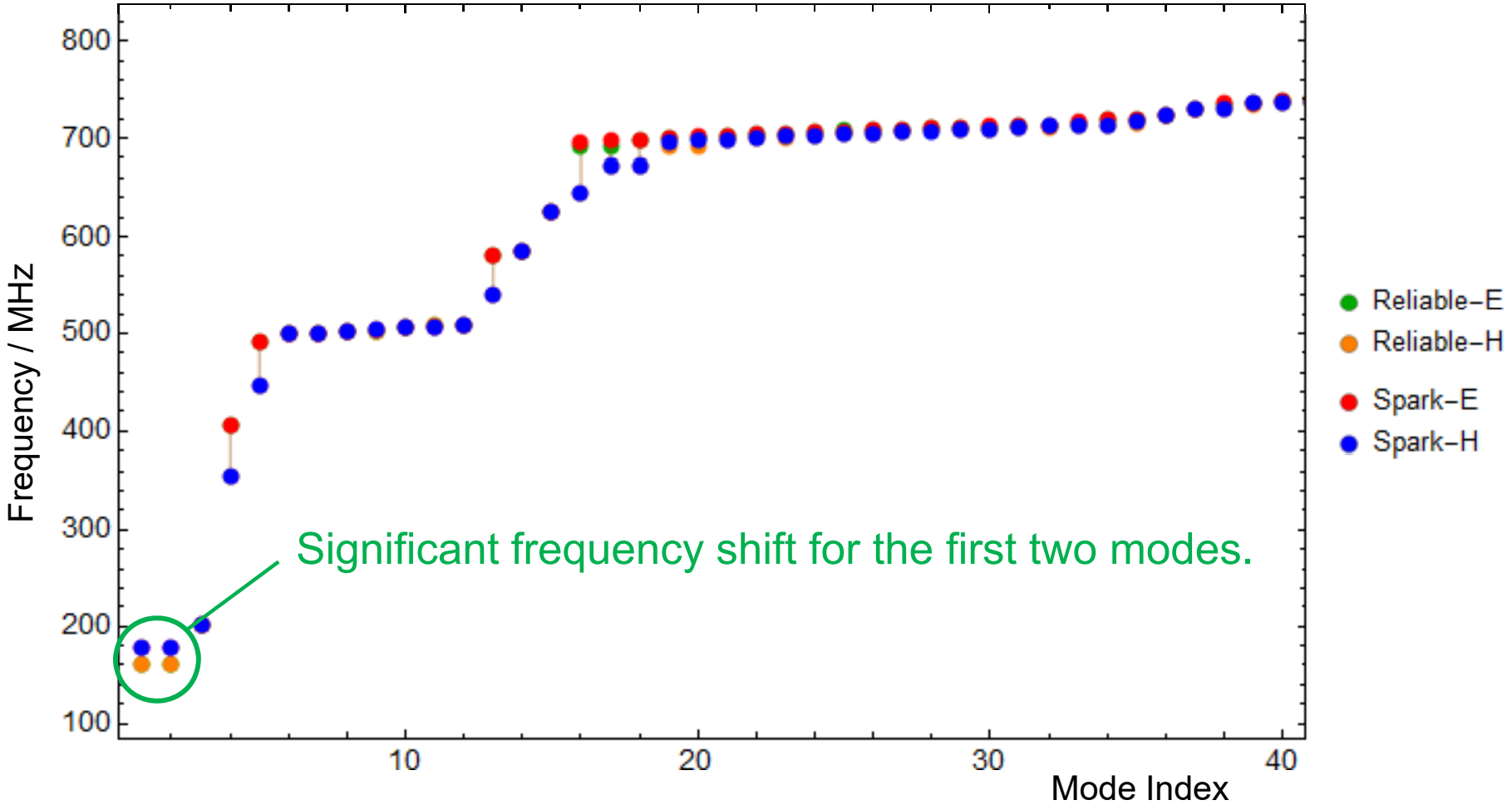
- Resonance Frequency (all calculated modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

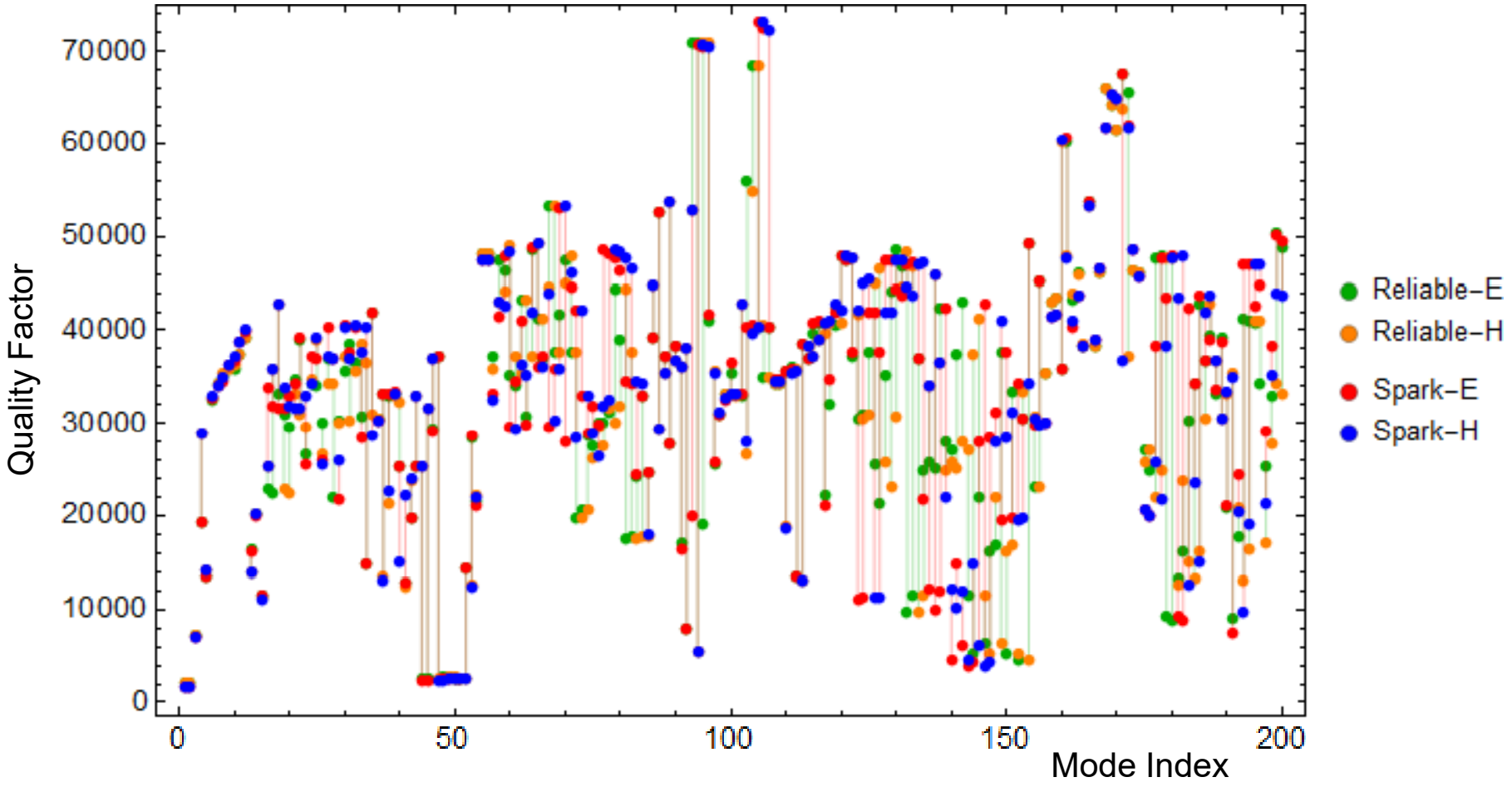
- Resonance Frequency (first forty modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

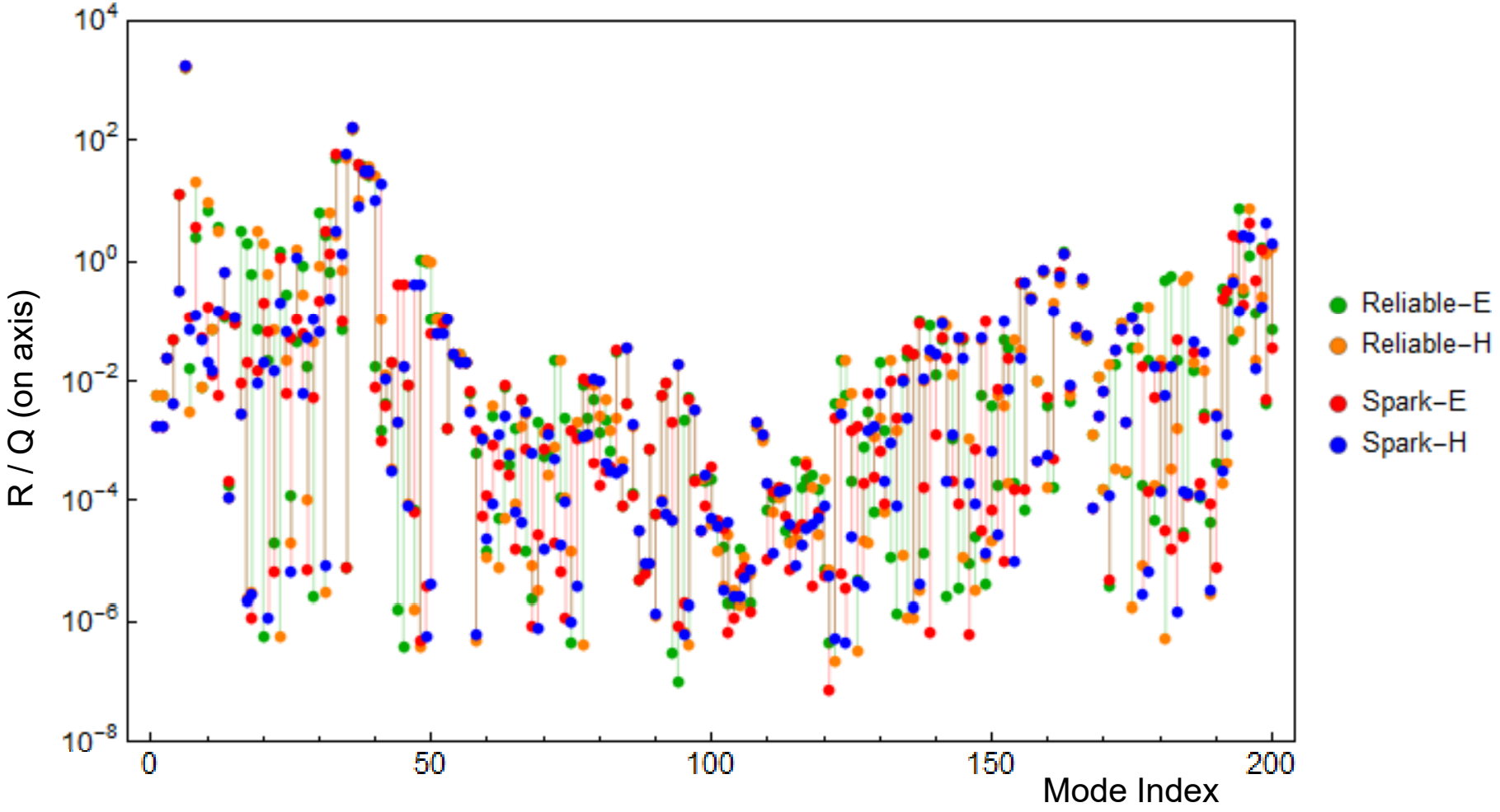
- Quality Factor (all calculated modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

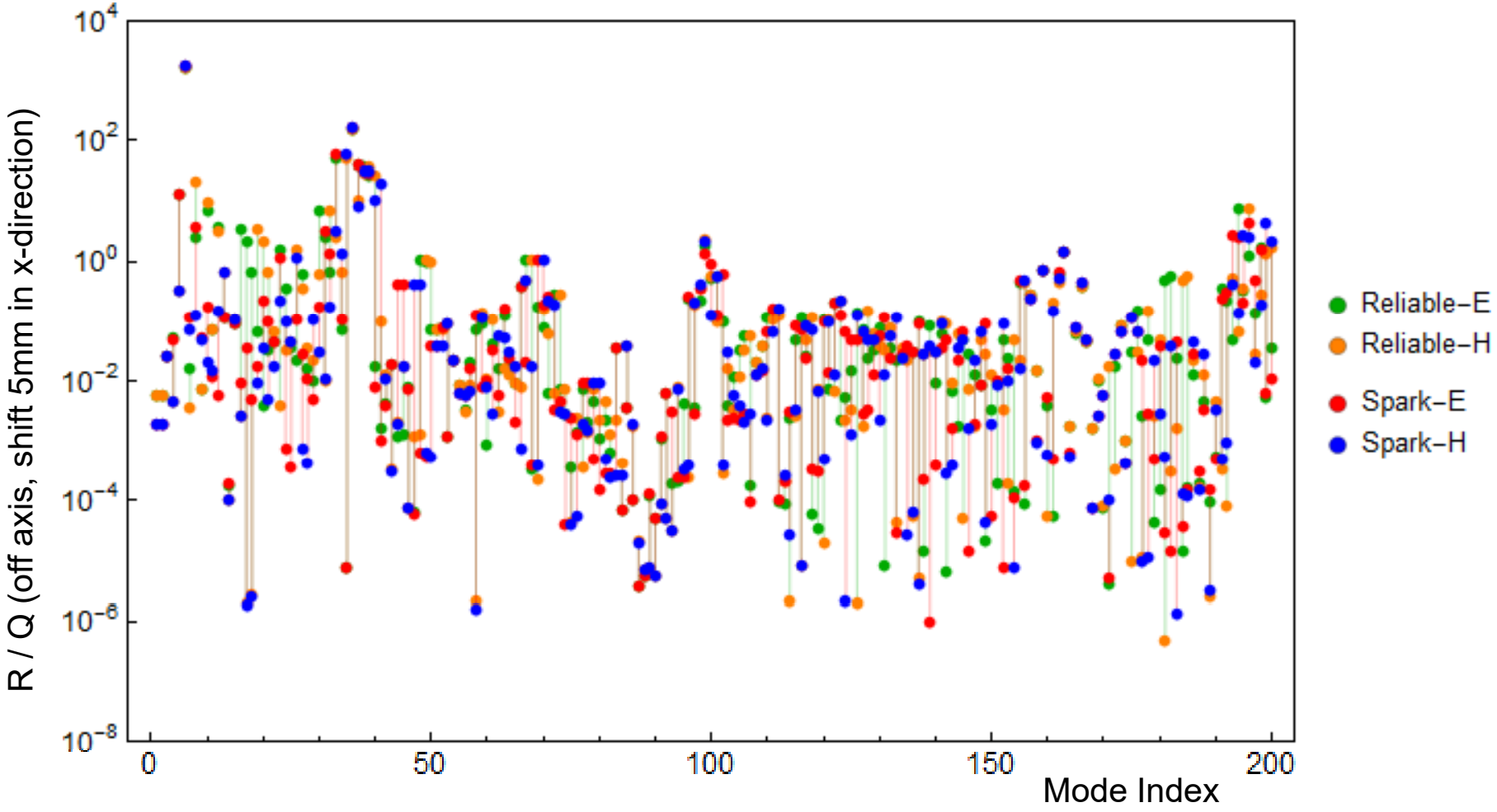
- On Axis R / Q (all calculated modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

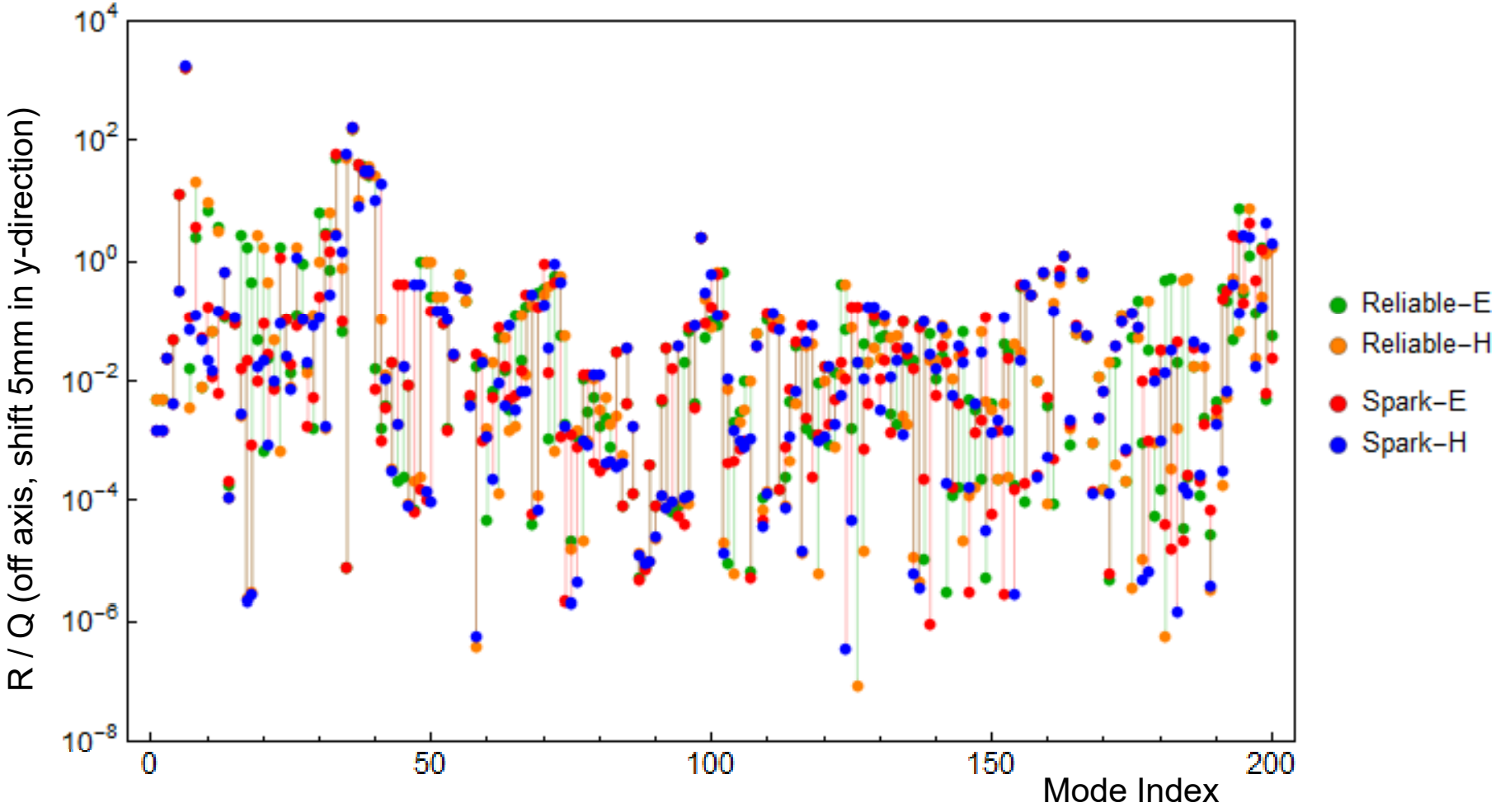
- Off Axis R / Q (all calculated modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

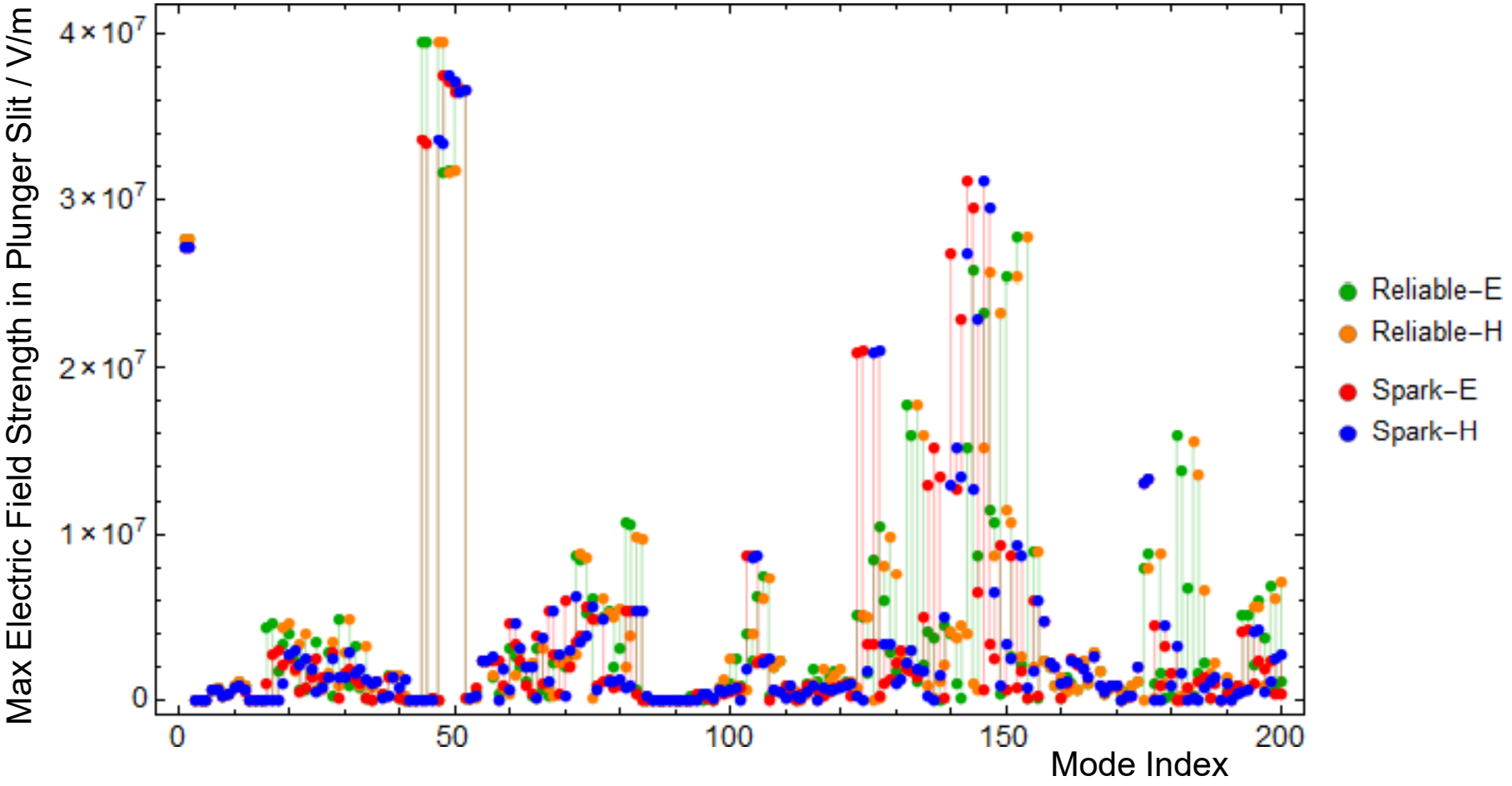
- Off Axis R / Q (all calculated modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

- Maximum Field Values in the Plunger Slits (all modes)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

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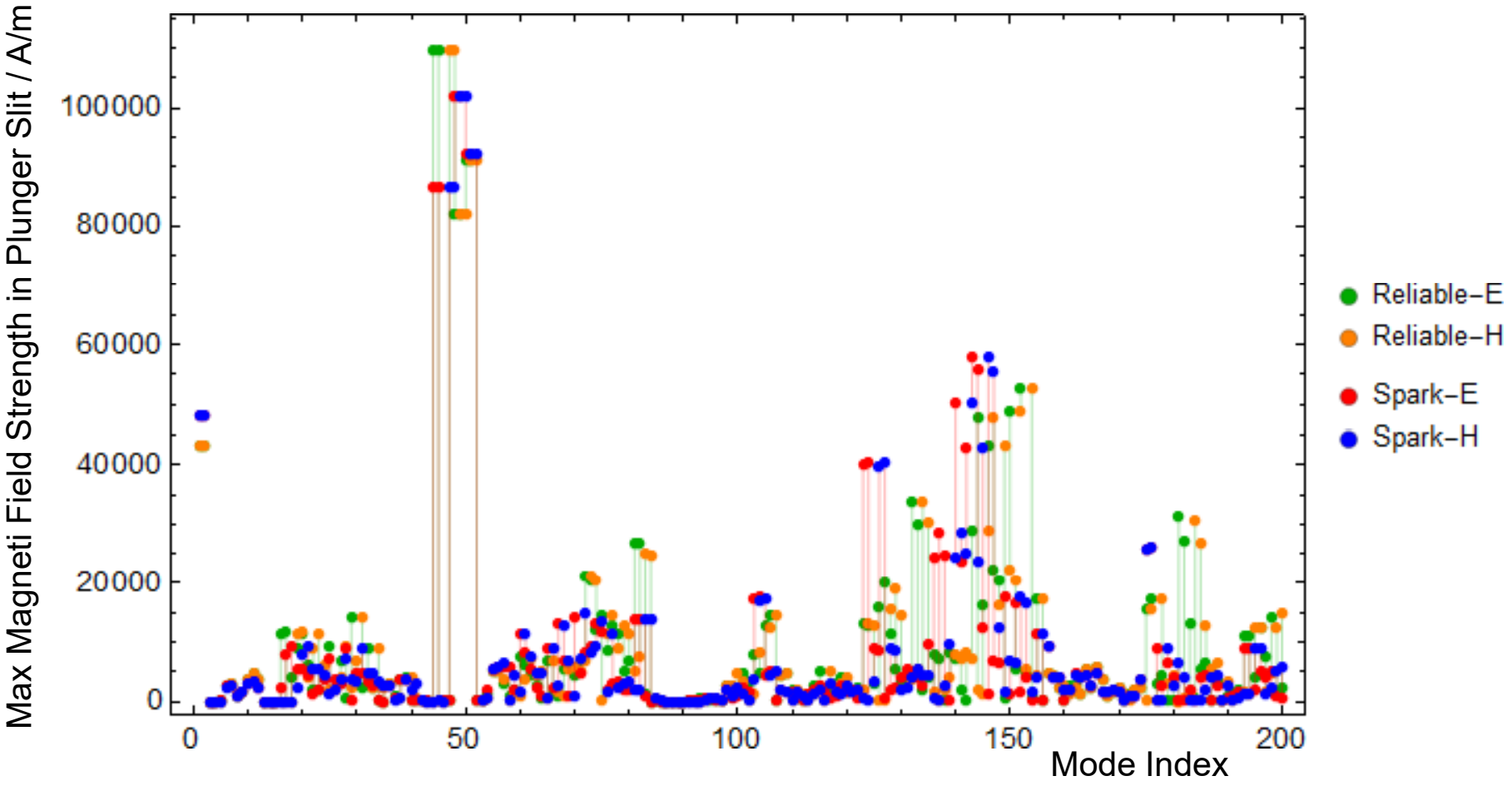
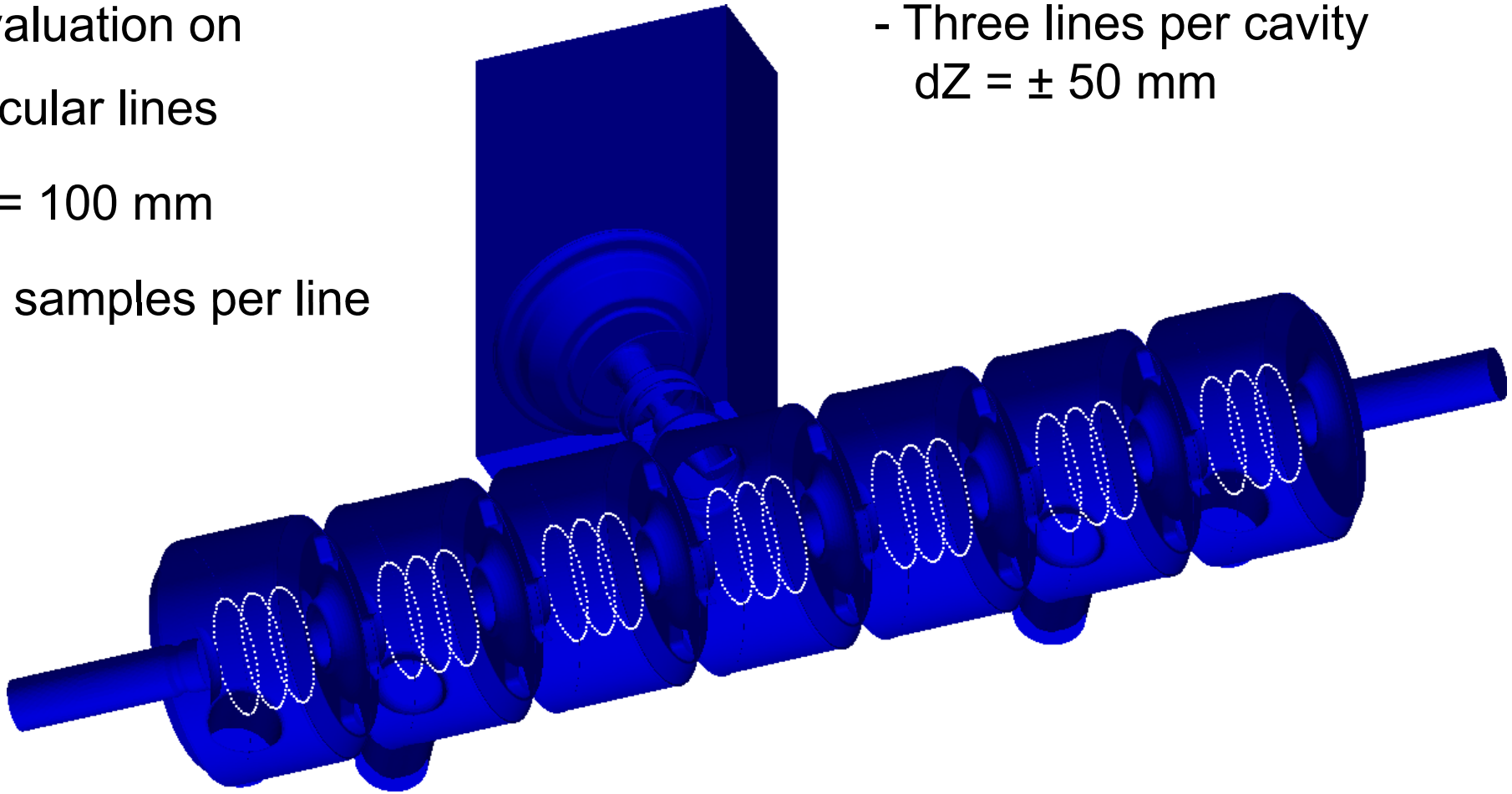


Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

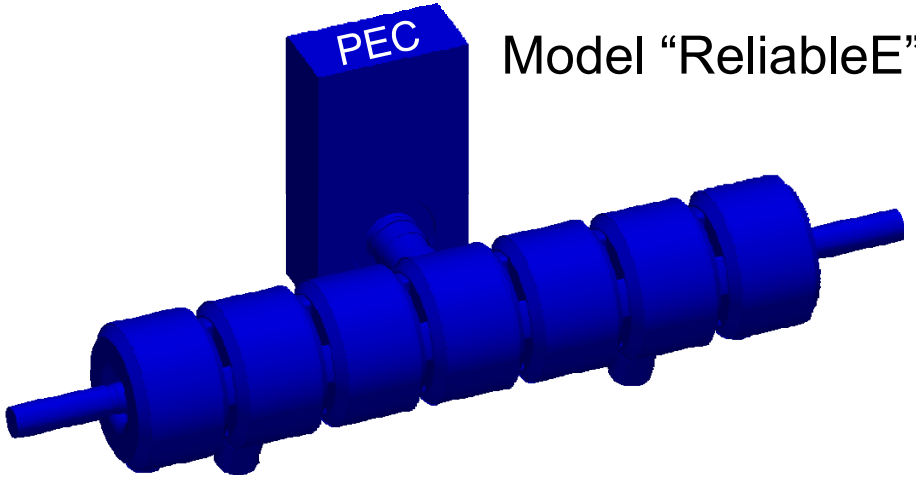
- Field Classification and Mode Correlation
  - Evaluation on circular lines
  - R = 100 mm
  - 60 samples per line
  - Three lines per cavity dZ = ± 50 mm



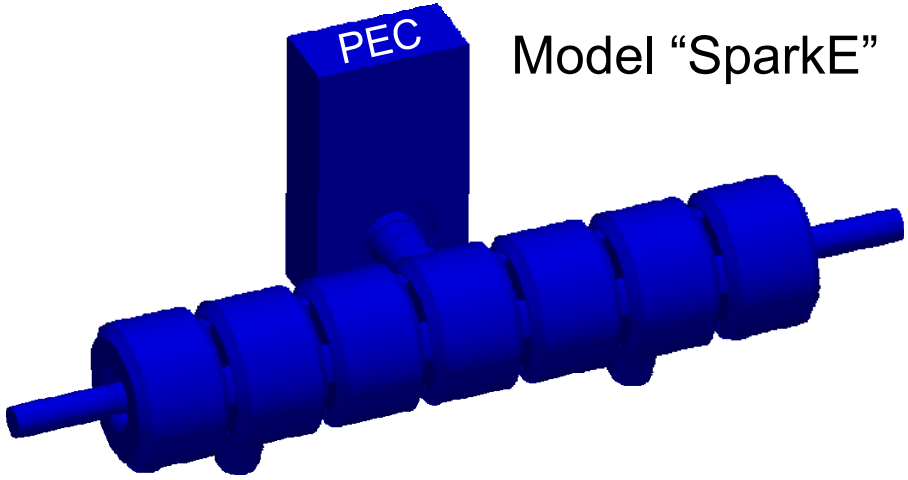
Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

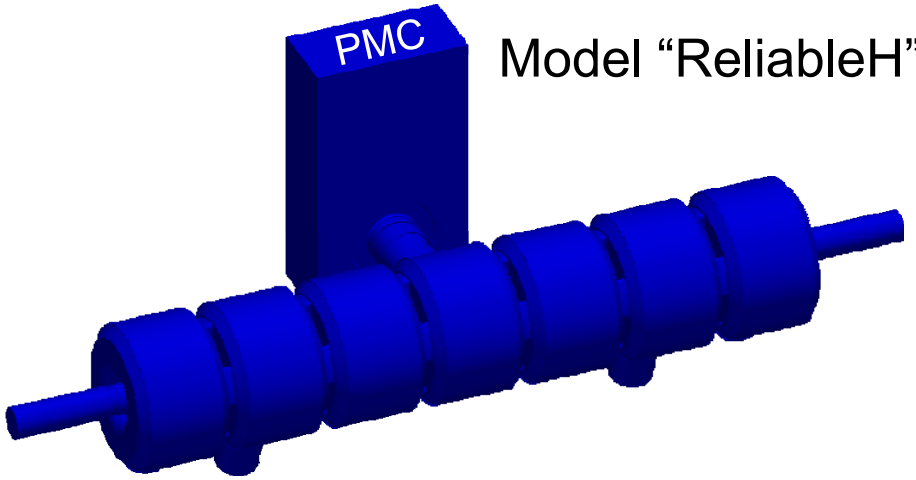
- Field Classification and Mode Correlation



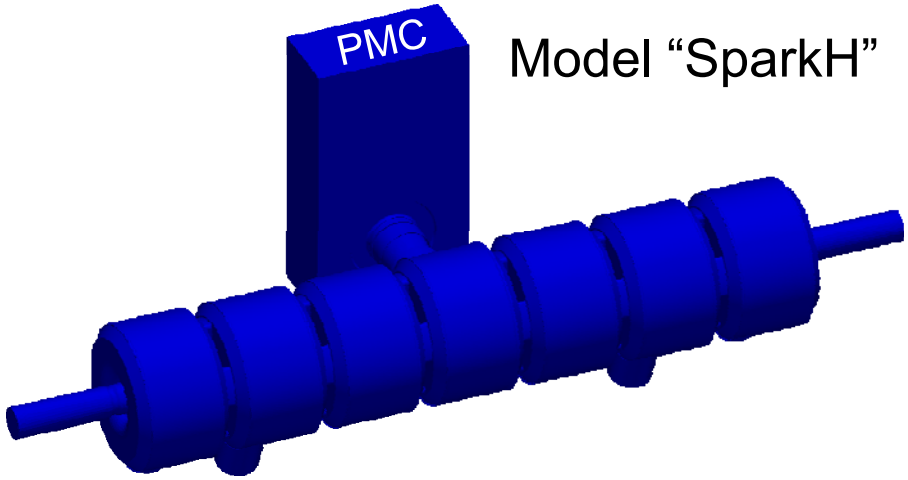
Model “ReliableE”



Model “SparkE”



Model “ReliableH”

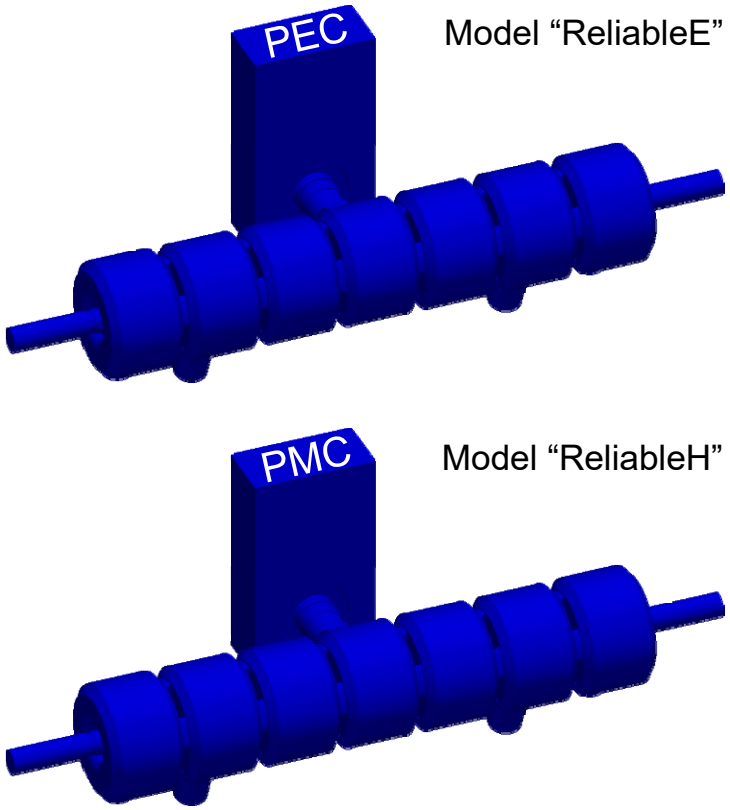


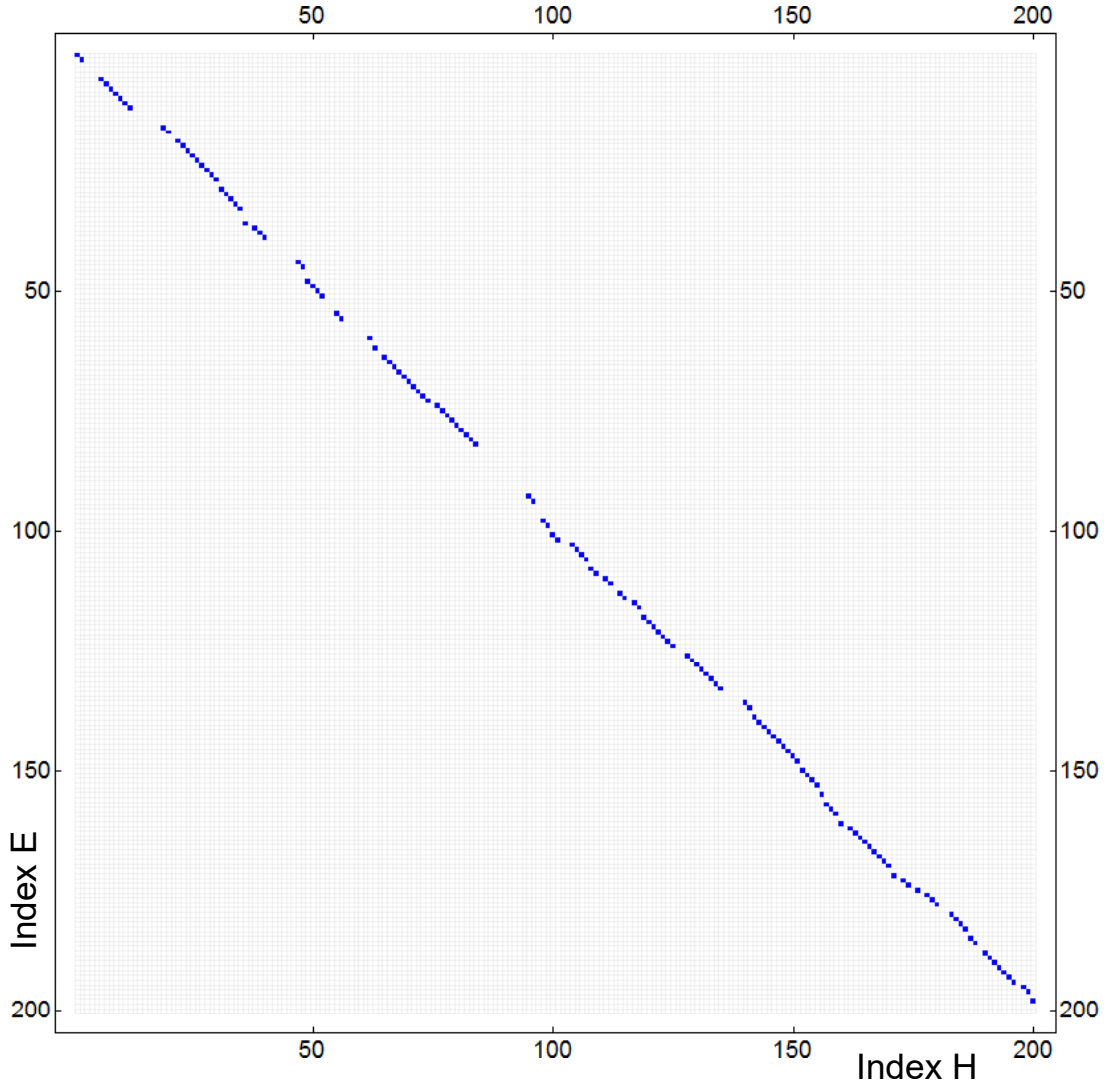
Model “SparkH”

Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

- Mode Correlation
  - Model “reliable”

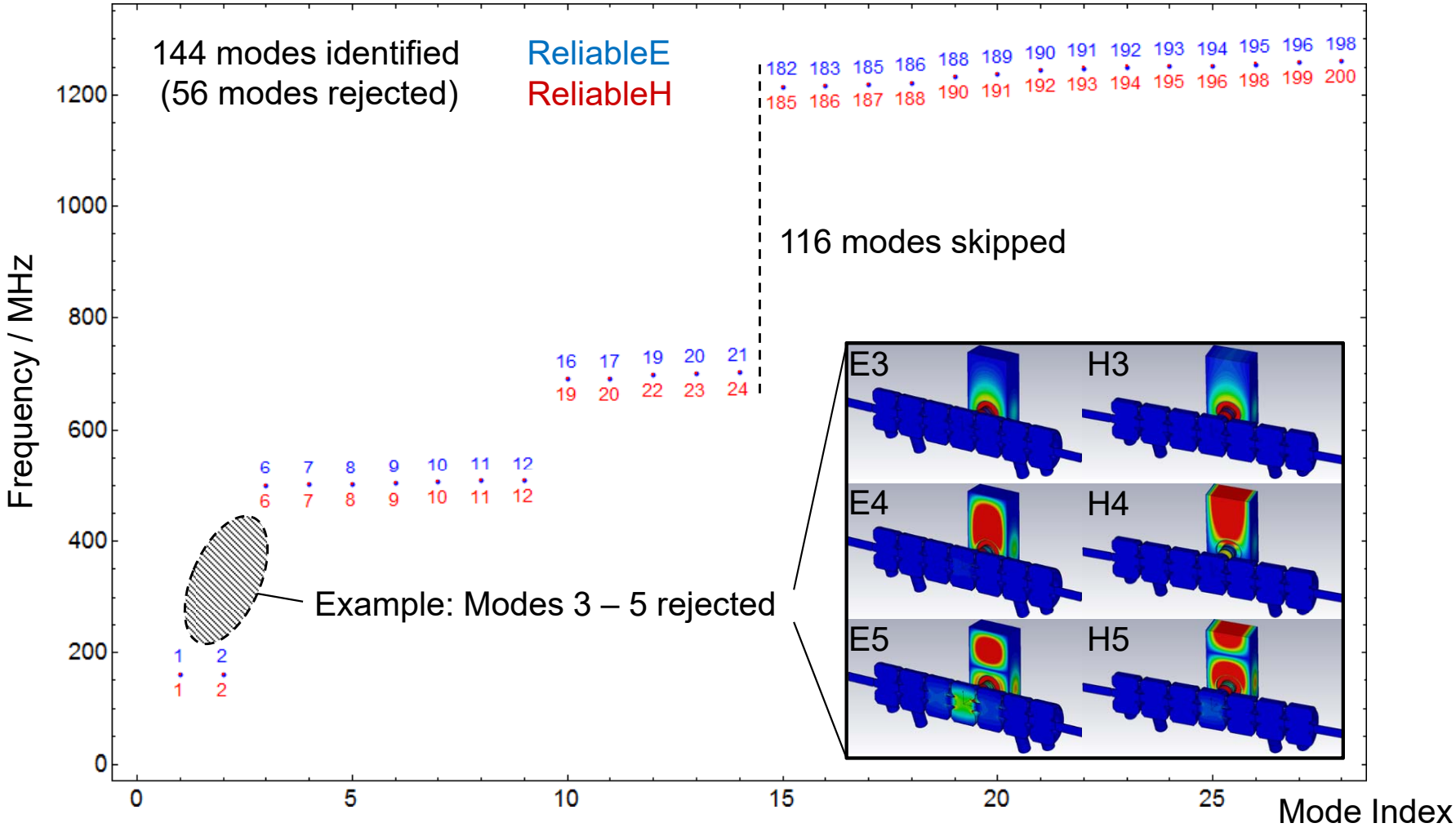




Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

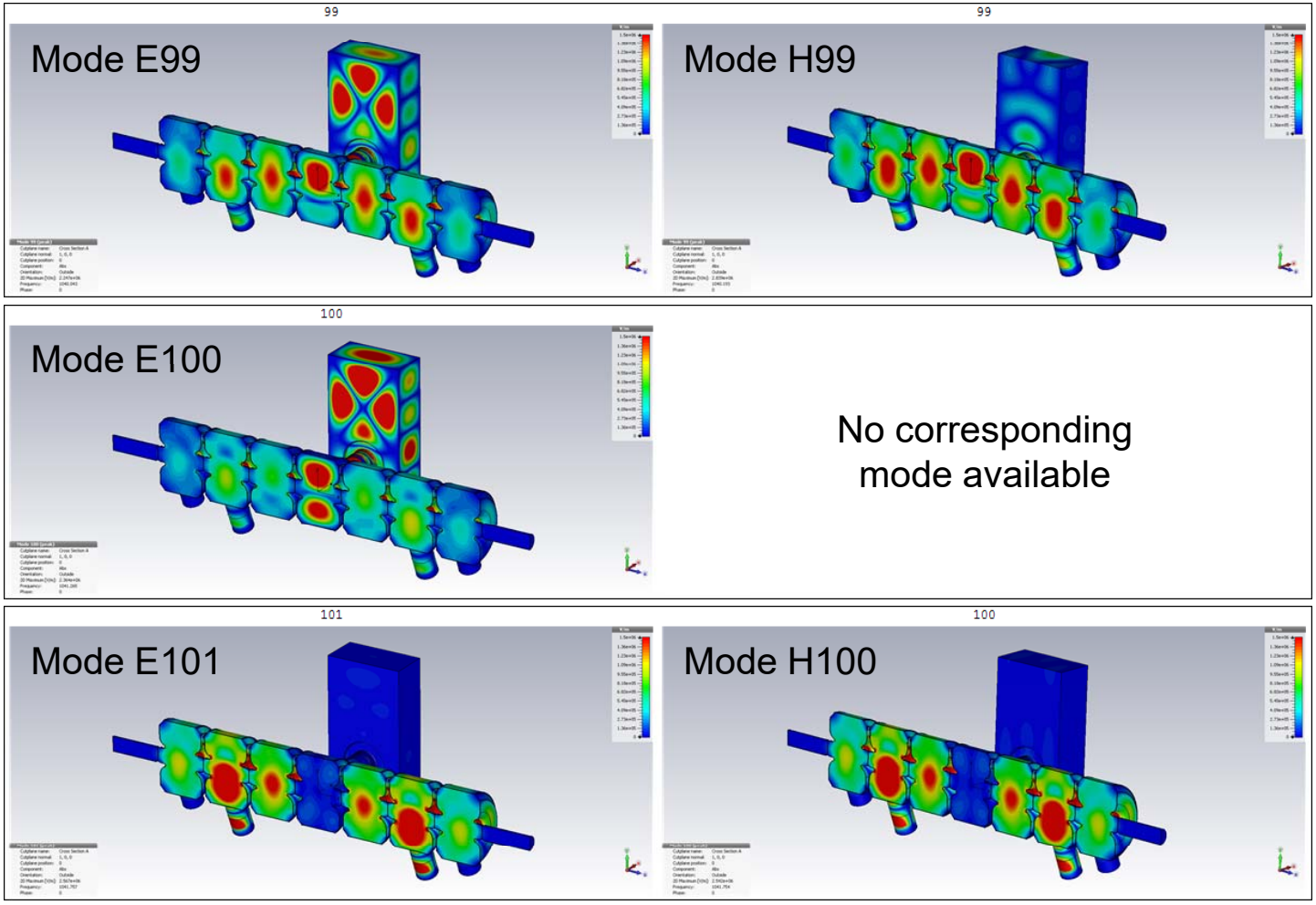
- Mode Correlation



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

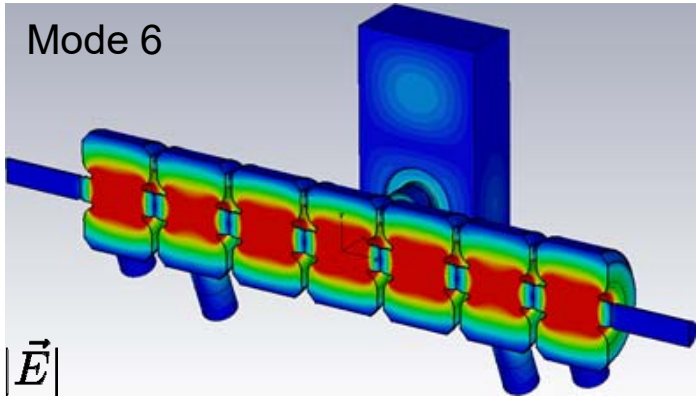
- Mode Correlation

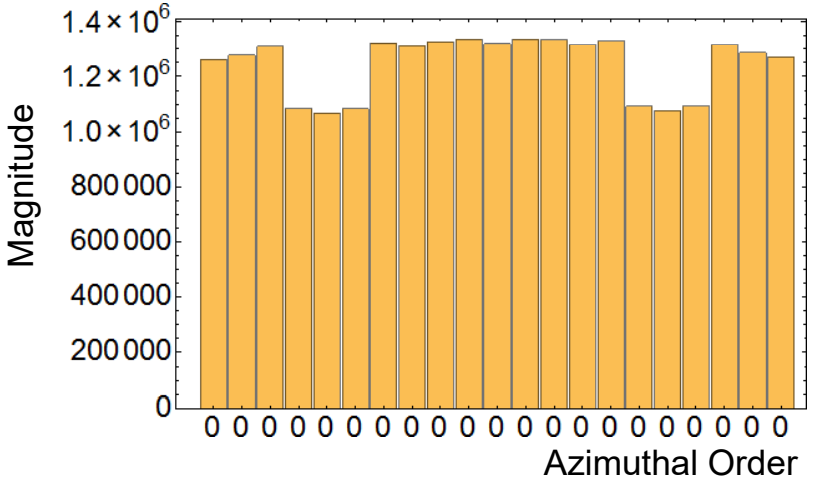


Simulation Results

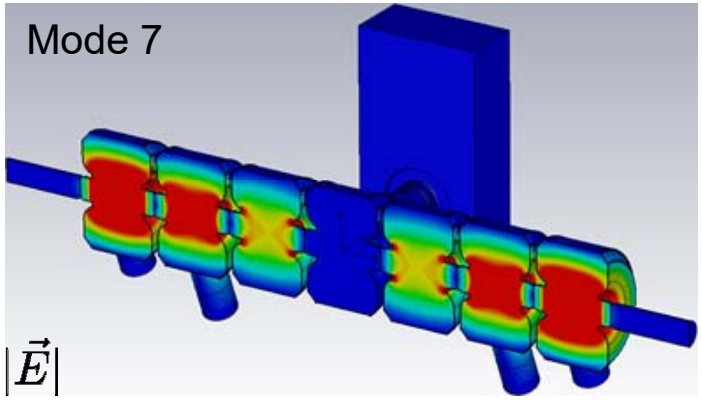
TECHNISCHE UNIVERSITÄT DARMSTADT

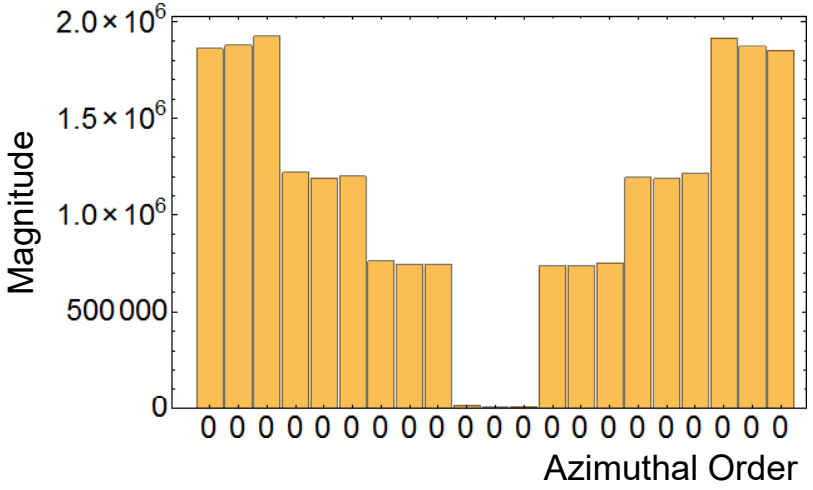
- Field Classification





➡ Monopole



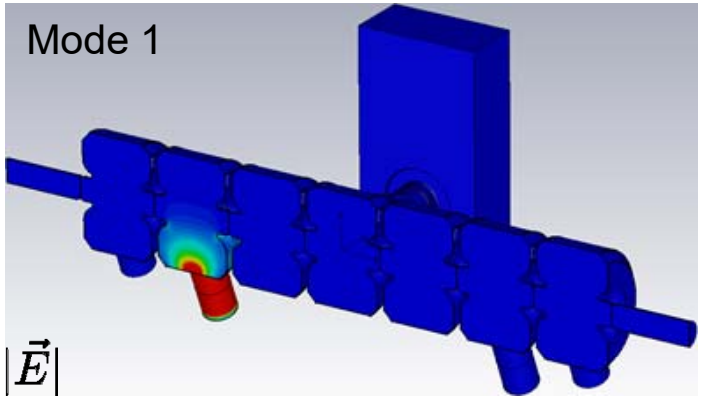


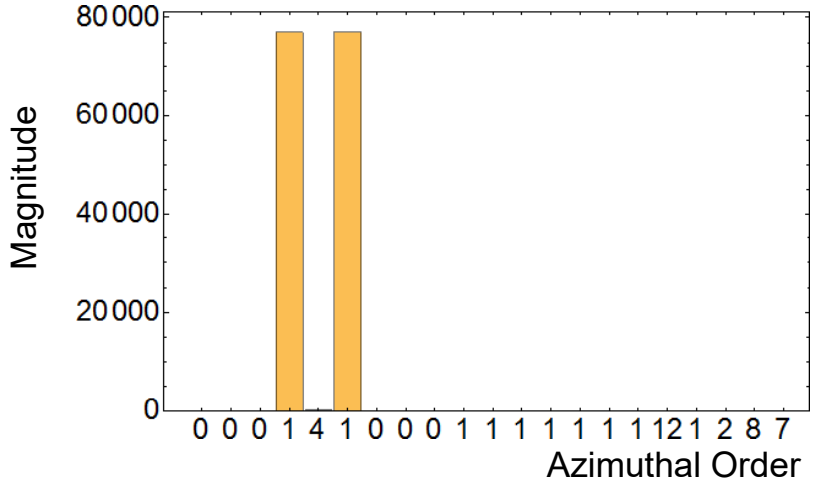
➡ Monopole

Simulation Results

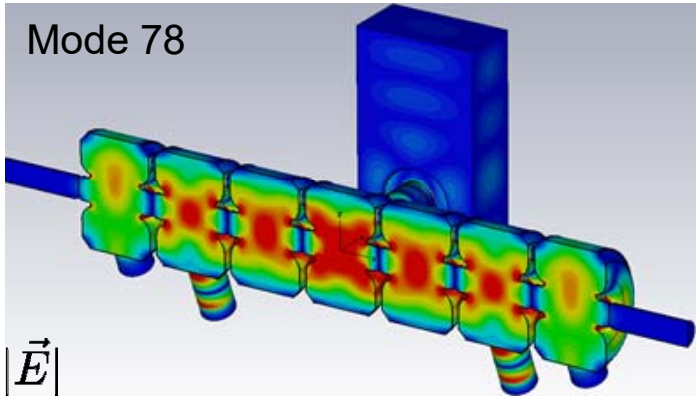
TECHNISCHE UNIVERSITÄT DARMSTADT

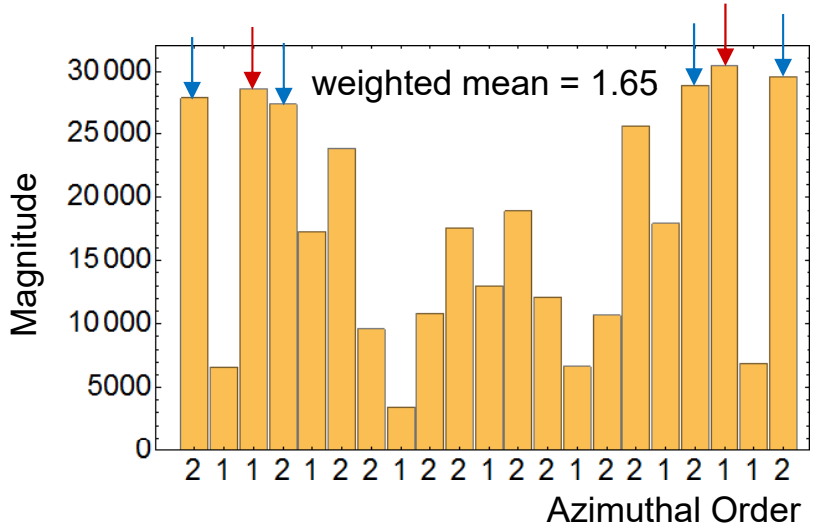
- Field Classification





➡ Dipole



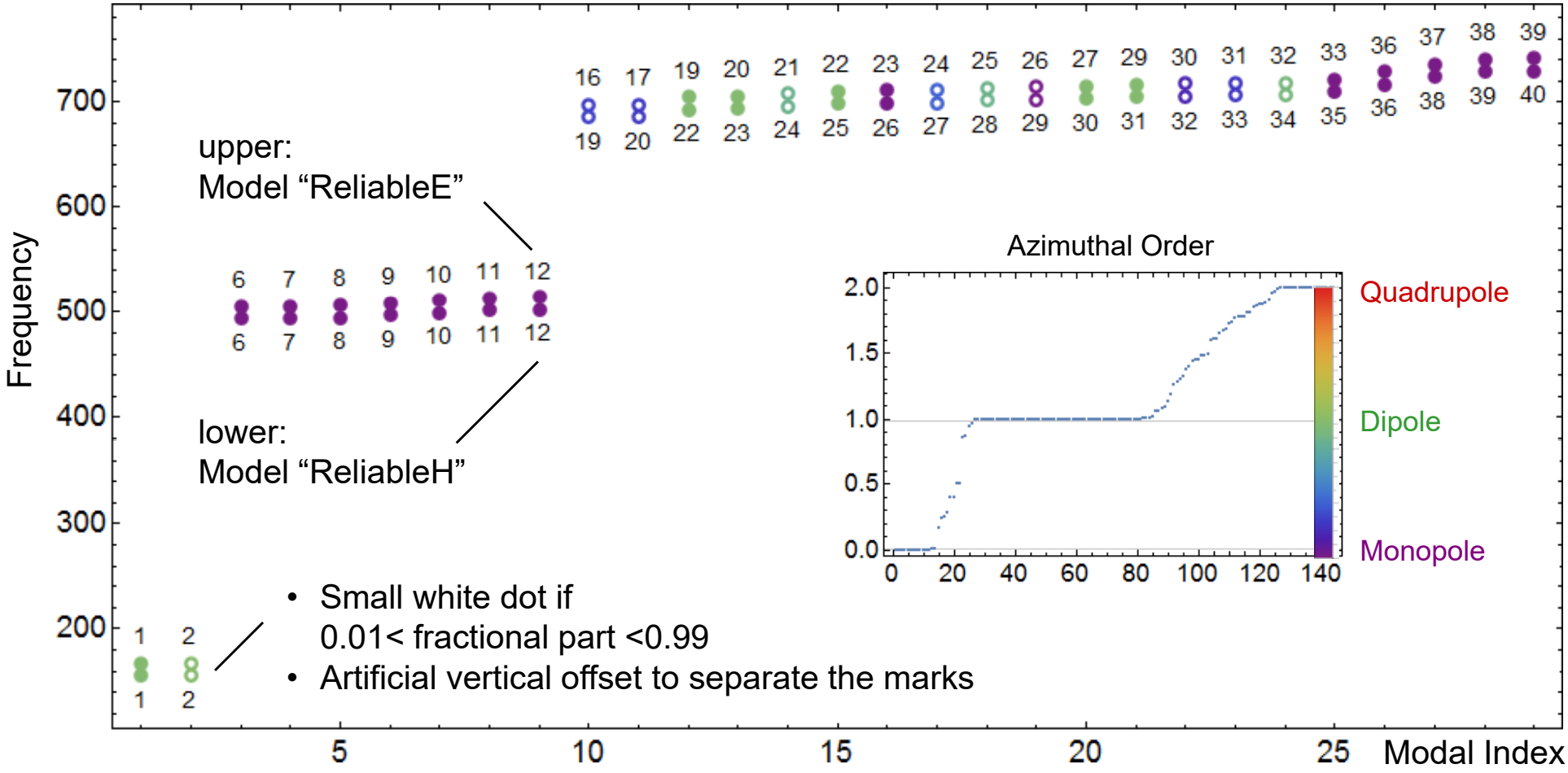


➡ Dipole?
Quadruople?

Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

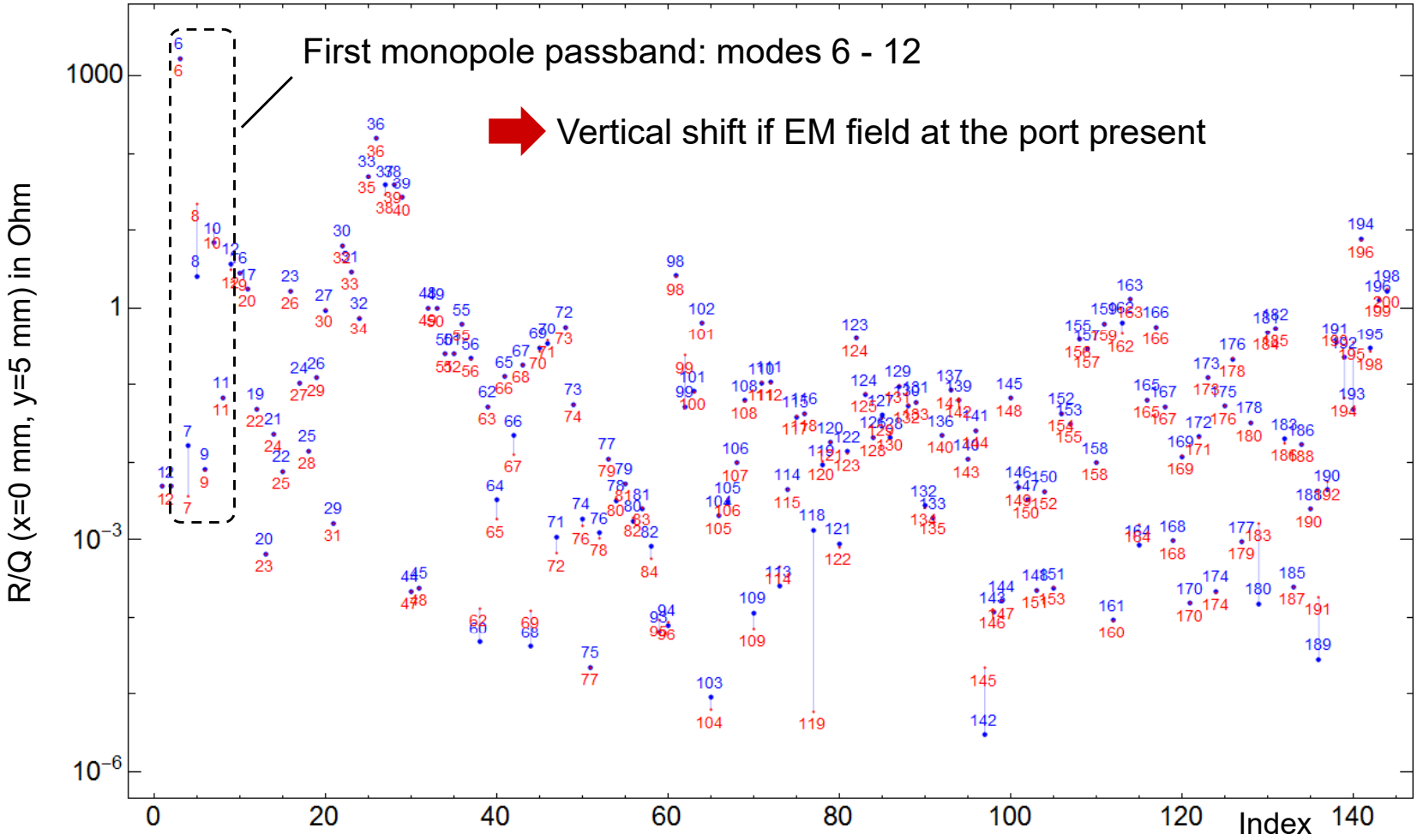
- Field Classification



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

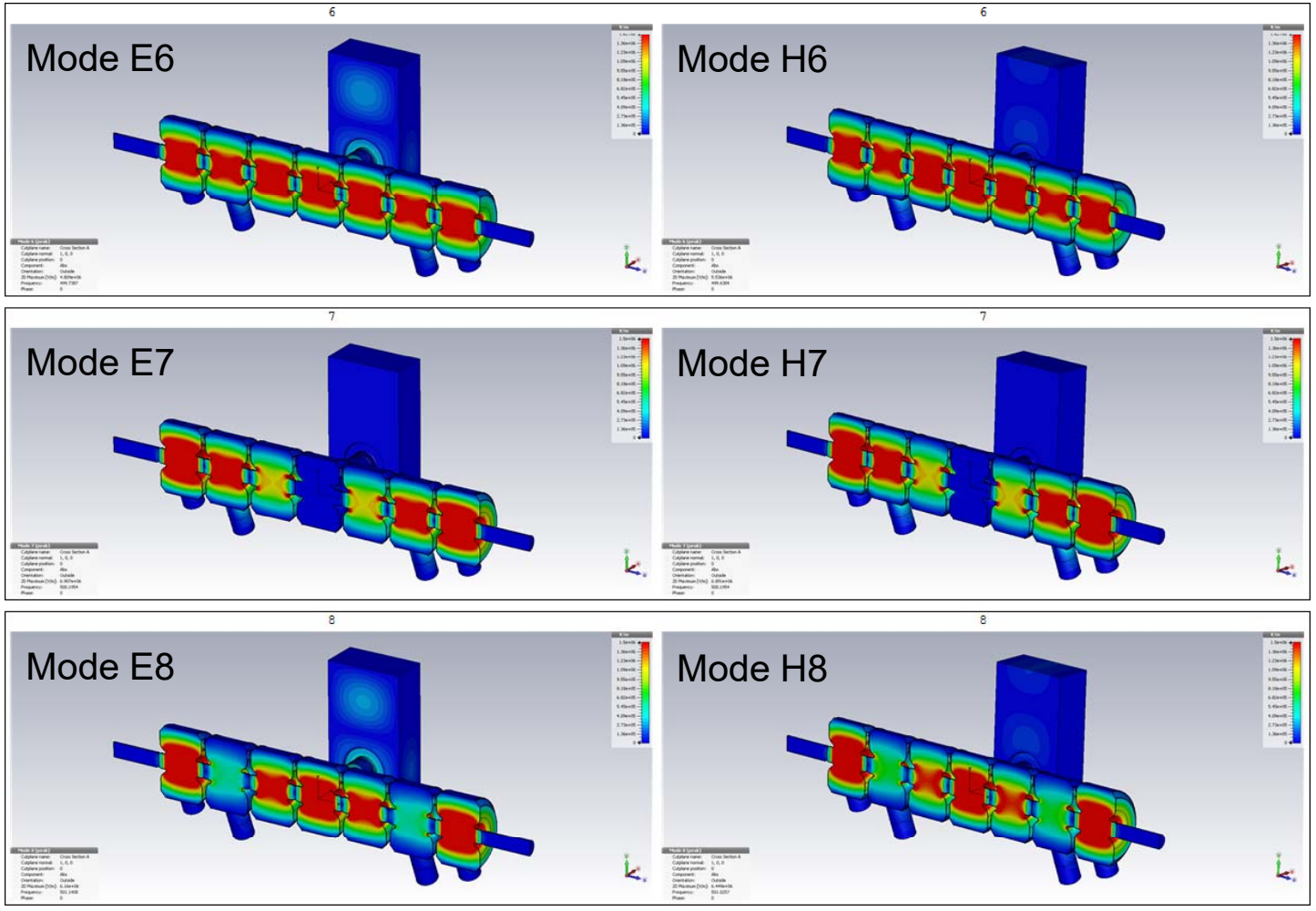
- Mode Correlation (“reliable E, reliable H”)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

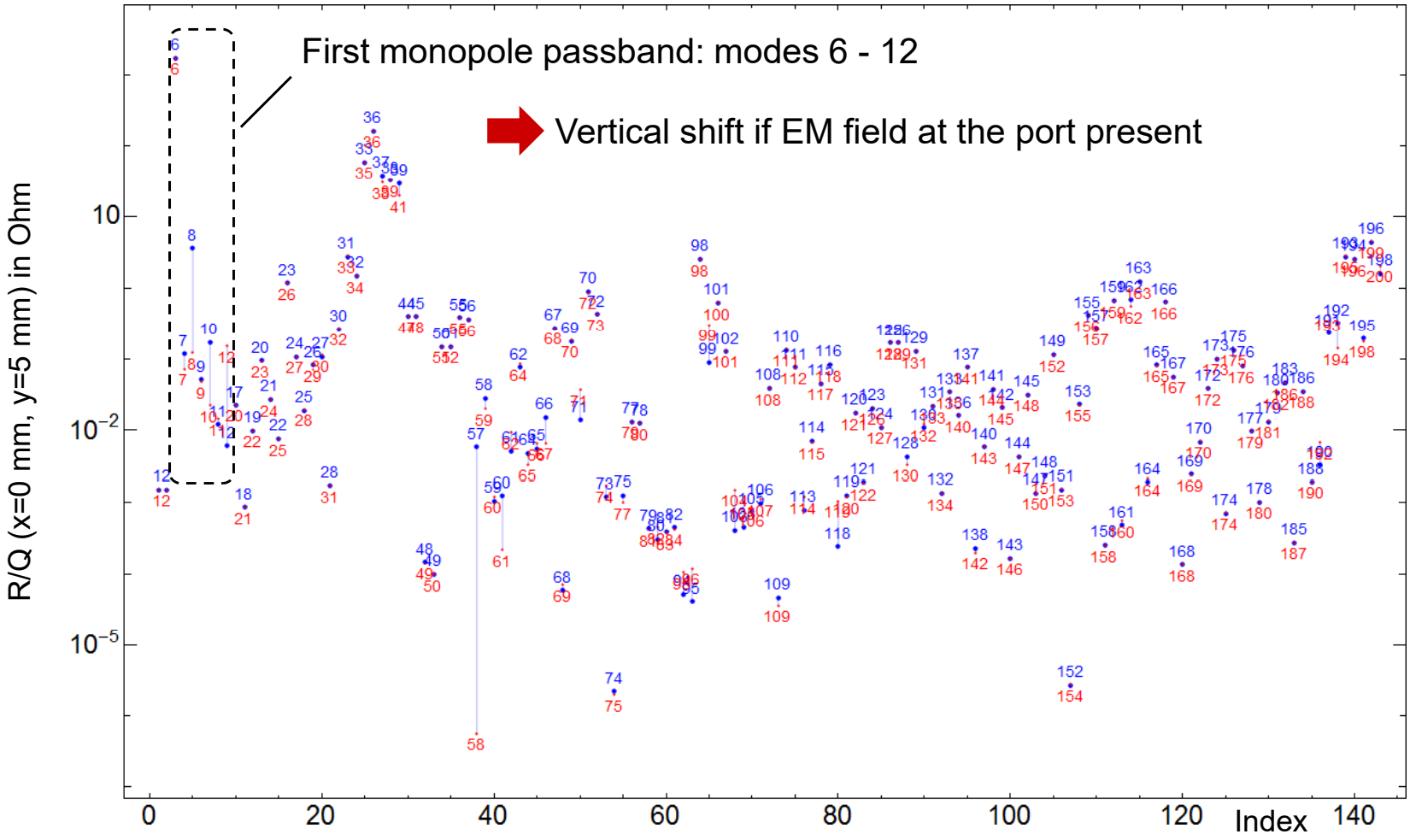
- Mode Correlation (“reliable E, reliable H”)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

- Mode Correlation (“spark E, spark H”)



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

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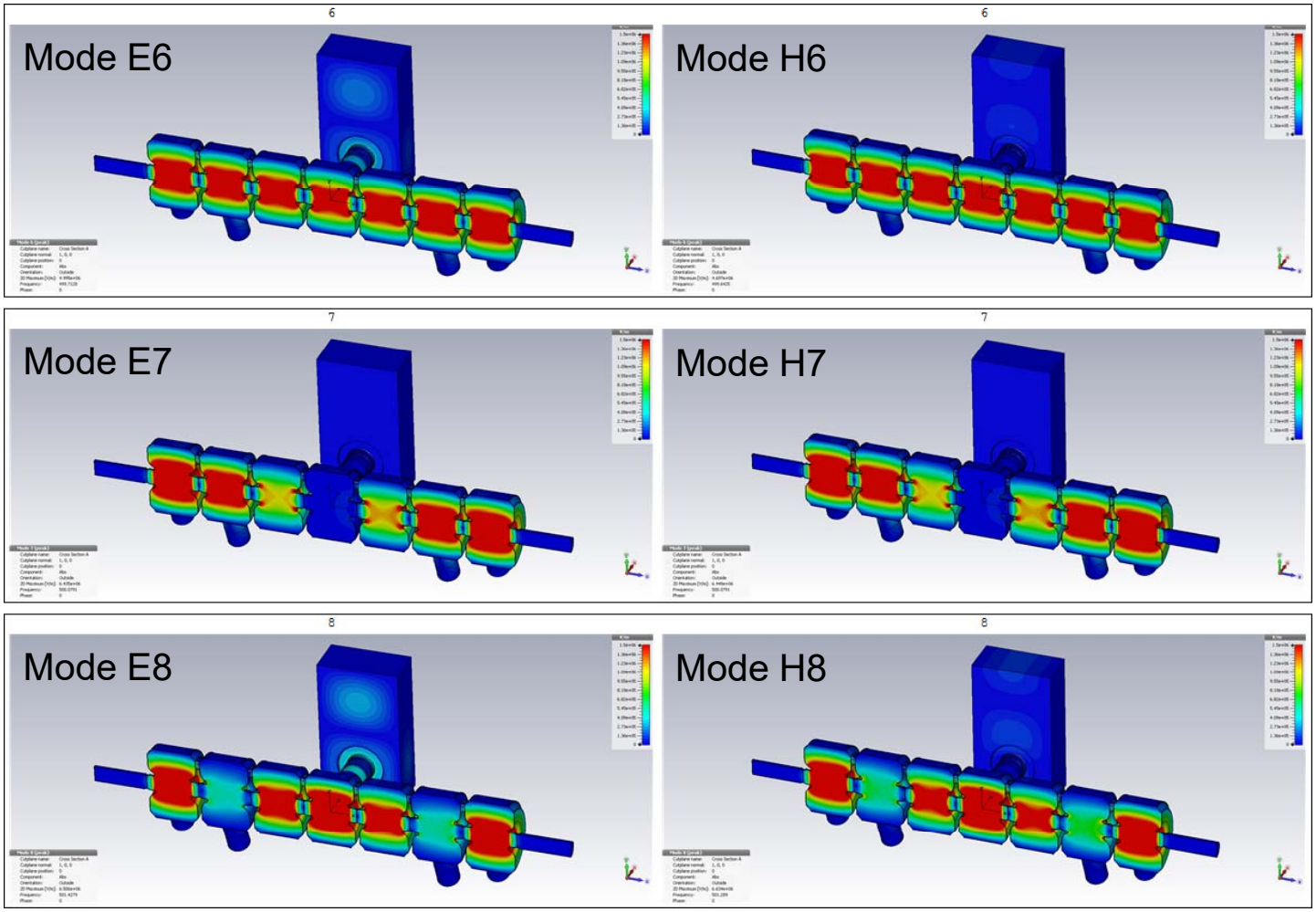
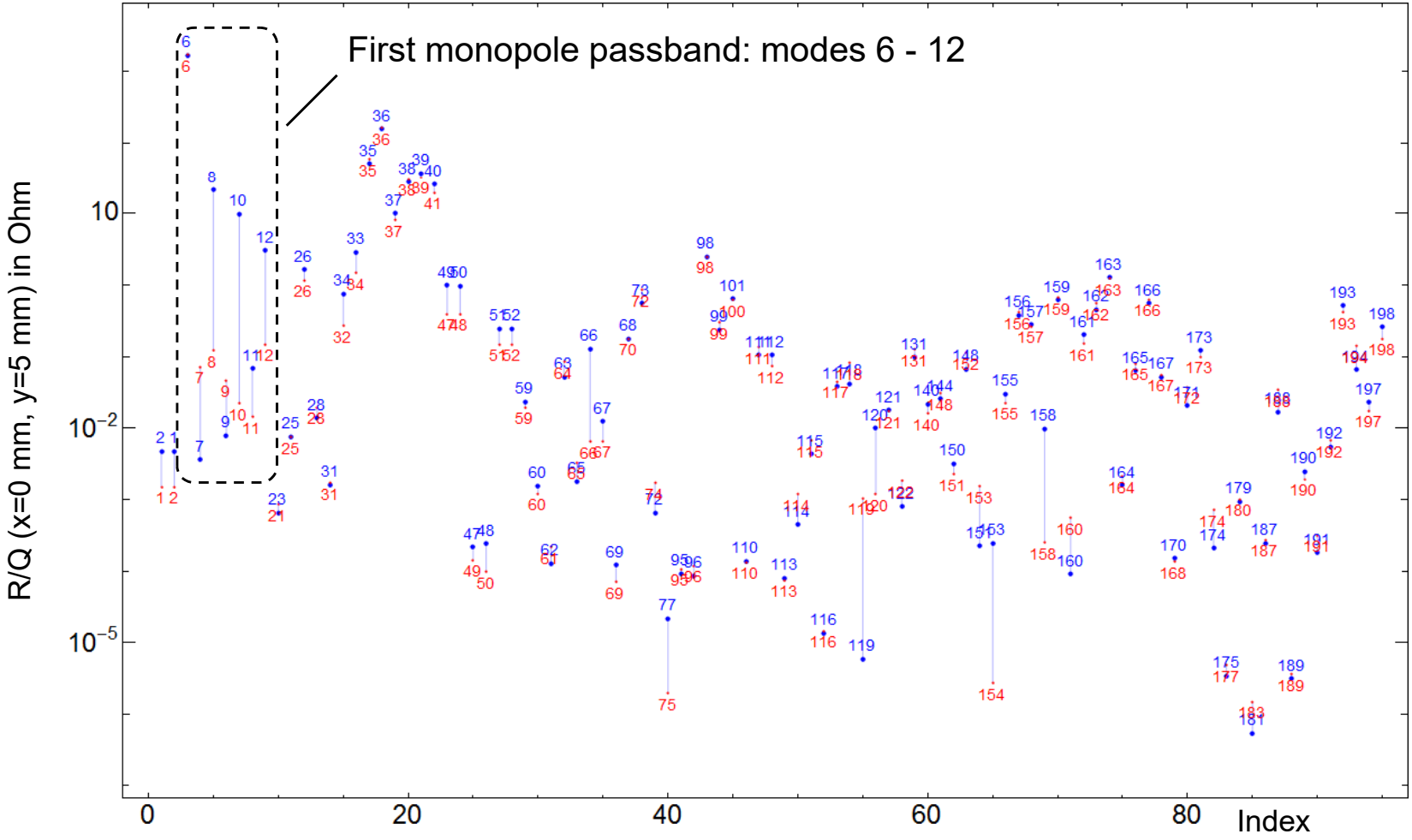


Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

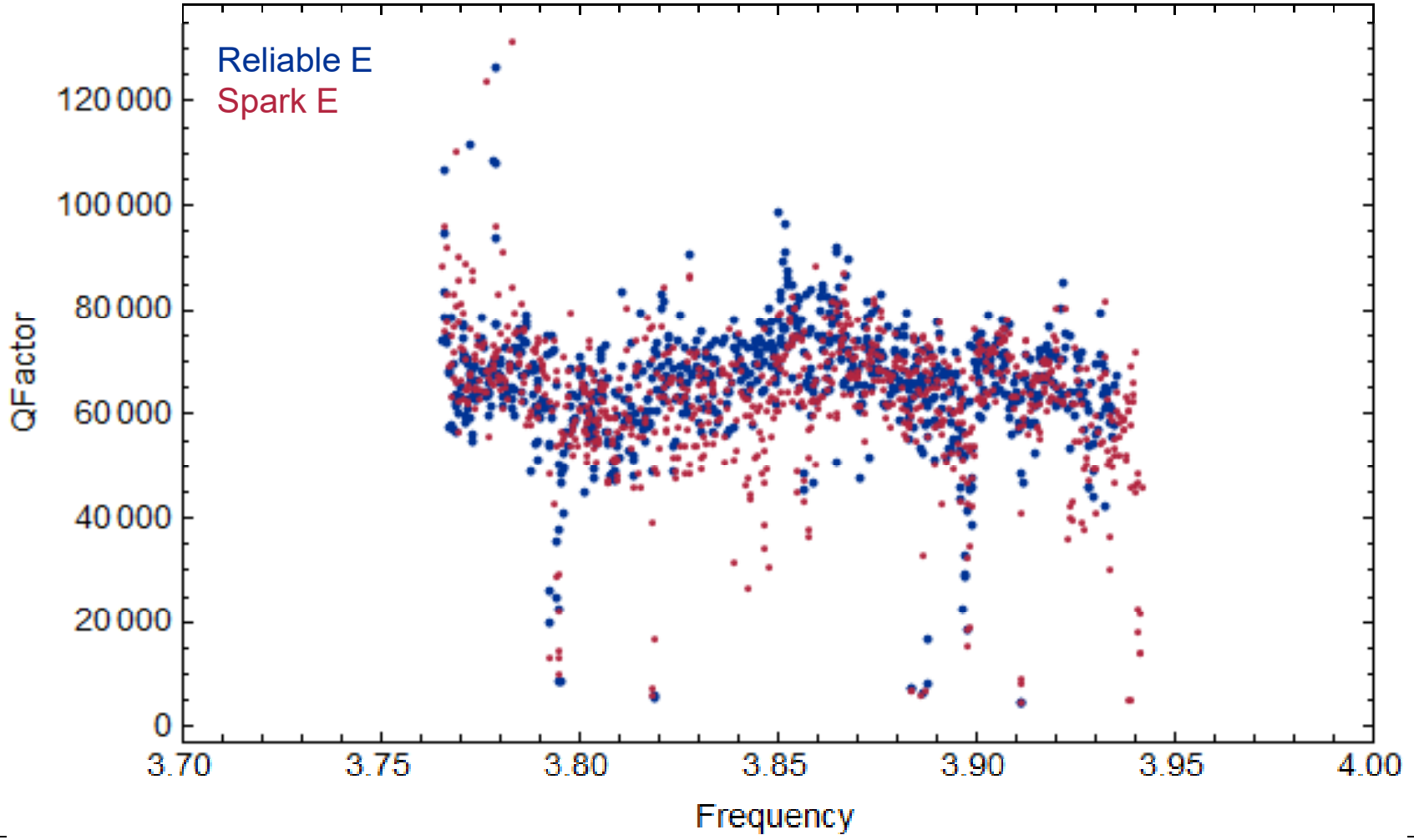
- Mode Correlation ("reliable H, spark H")



Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

- Eigenmodes in the Frequency Range from 3.8 to 3.9 GHz



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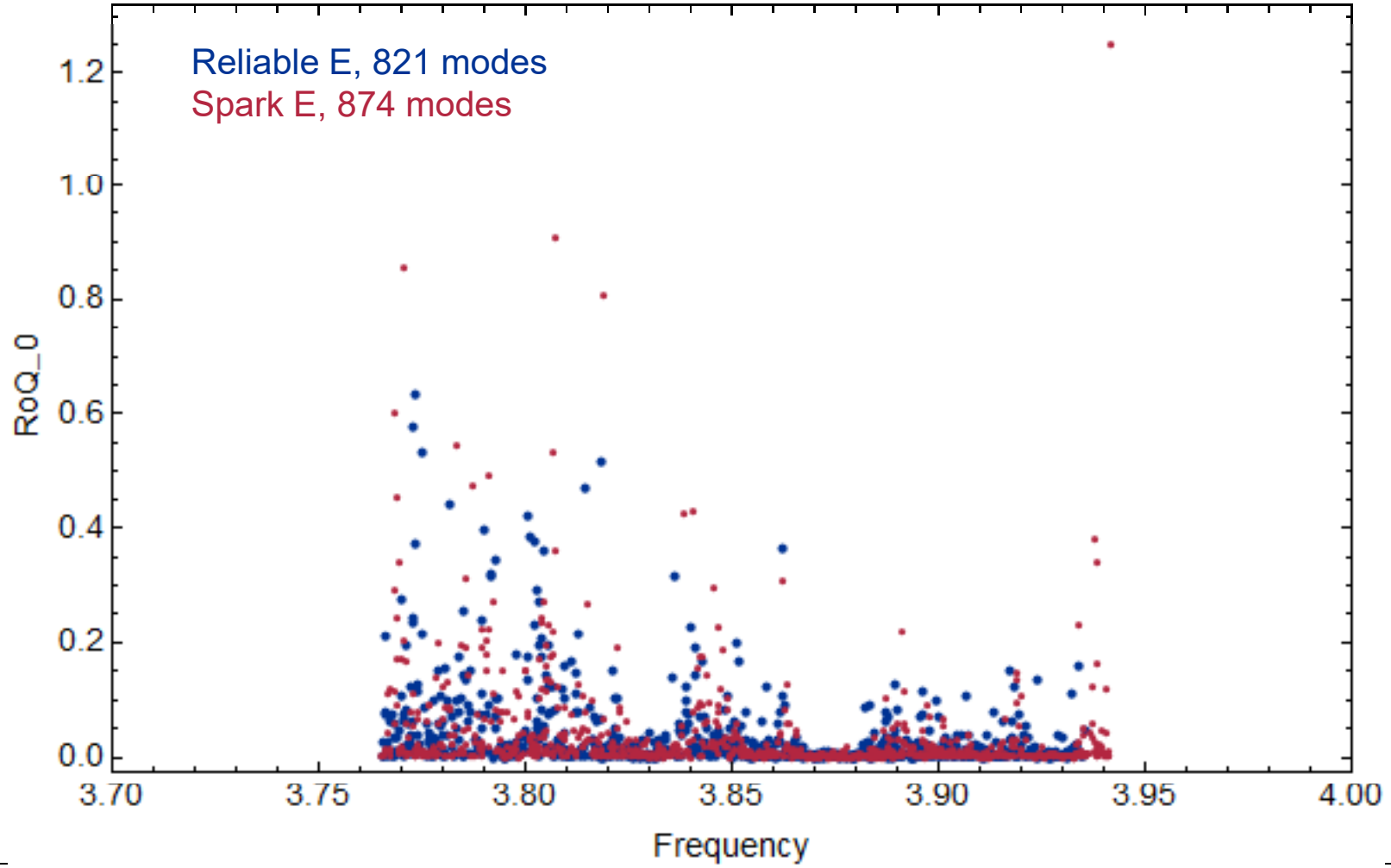

Simulation Results

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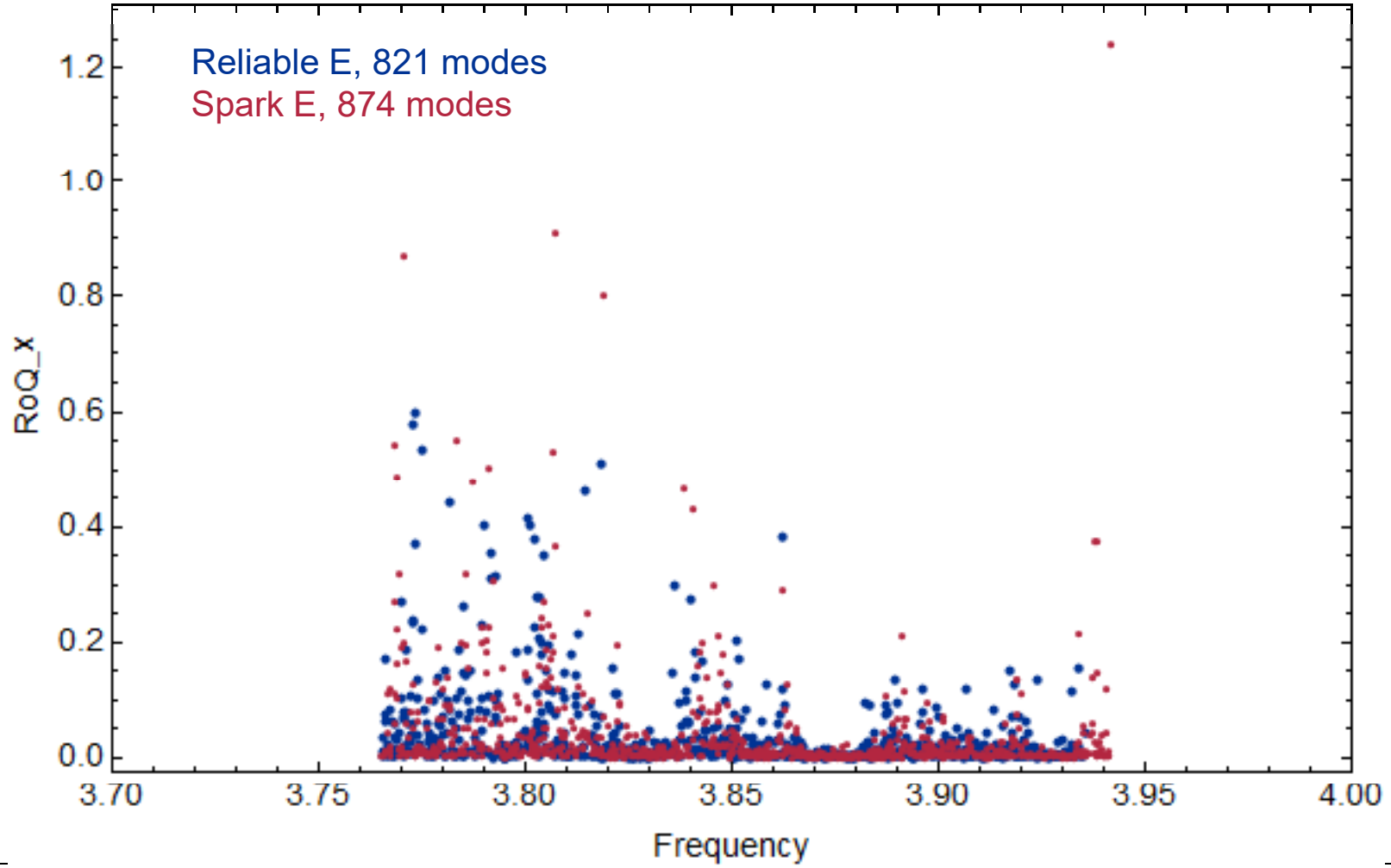

Simulation Results

TECHNISCHE UNIVERSITÄT DARMSTADT

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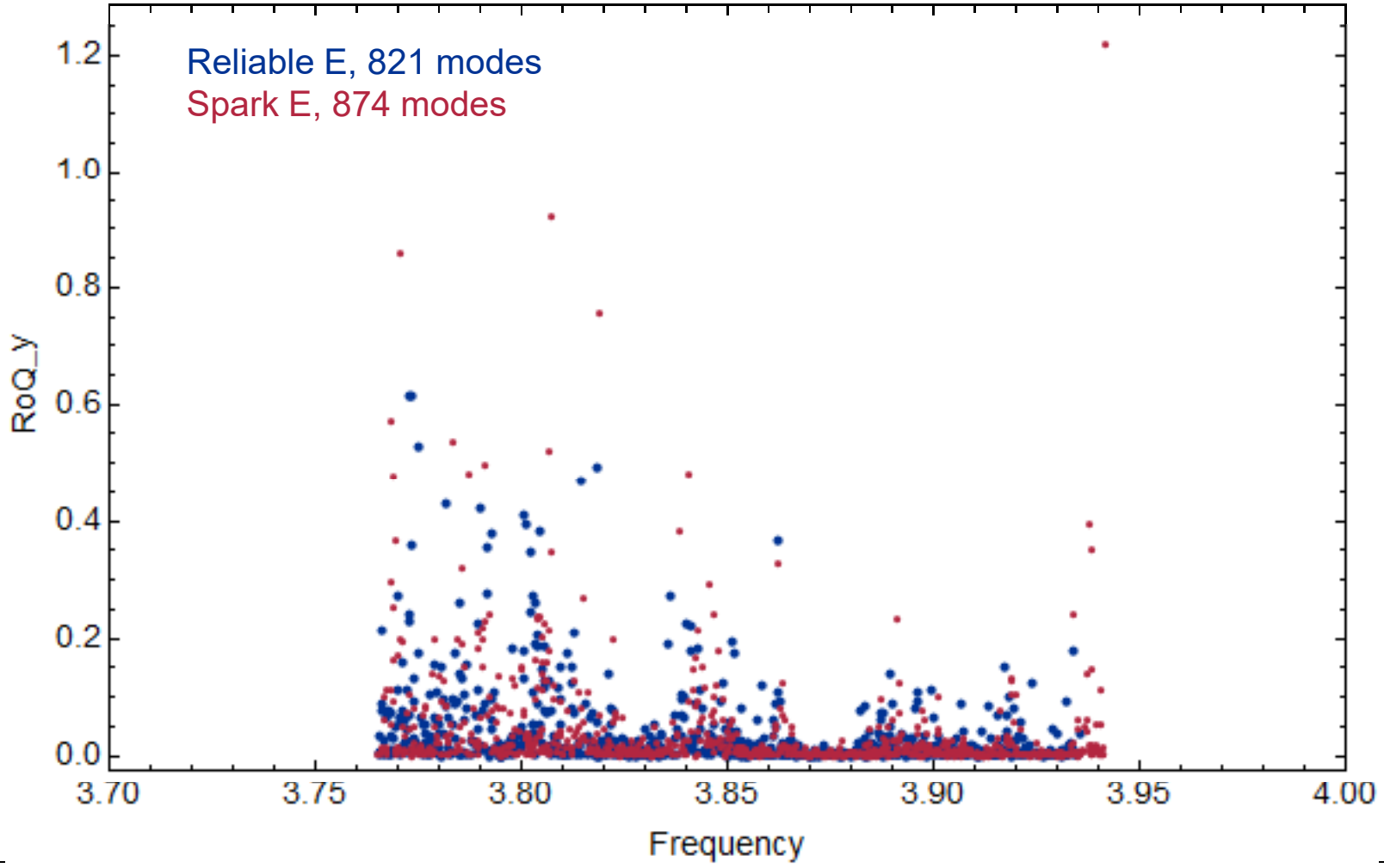

Outline

TECHNISCHE UNIVERSITÄT DARMSTADT

- Motivation
- Computational Model
  - Drawings and geometry information
  - Numerical problem formulation
- Cavity tuning
  - Cell radius variation for the “reliable” and “spark” models
- Simulation results
  - Mode pattern and characteristic data for the “reliable” and “spark” models
- Summary / Outlook

Summary / Outlook

TECHNISCHE UNIVERSITÄT DARMSTADT

- Summary:
  - Precise modeling of the PETRA III cavity including pump ports, tuning plunger and input coupler
  - Eigenmode analysis performed up to 1.2 GHz (mode pattern, frequency, R/Q, Q via power loss, slit field)
  - Mode classification w.r.t. the azimuthal order
  - R/Q of the fundamental monopole passband sensitive to model change from “spark” to “reliable”
- Outlook:
  - Calculation of monopole passband with port BC?