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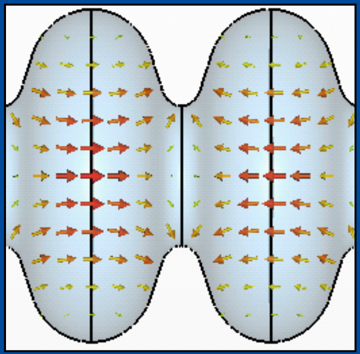

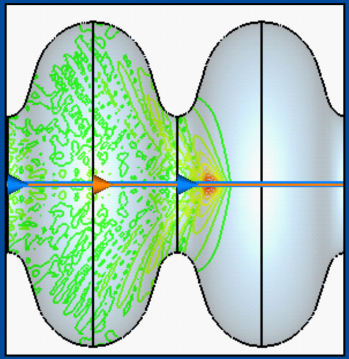

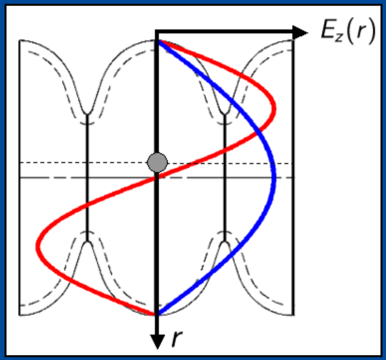

WP 10.5.3.: HOM Geometrical Dependencies Experimental Results and Simulations

Thomas Flisgen, Hans-Walter Glock and Ursula van Rienen

EUCARD Annual Review Meeting 2011

IPN Orsay, 05th of May 2011

Outline

- Motivation
- Roadmap
- Measurement and simulation of S-parameters of ACC39
- Sketch of a coupling scheme for computation of beam excited HOM signals based on CSC
- HOM signal detection using diode downmixing scheme (not funded by EuCARD, but closely related)
- Summary and future plans

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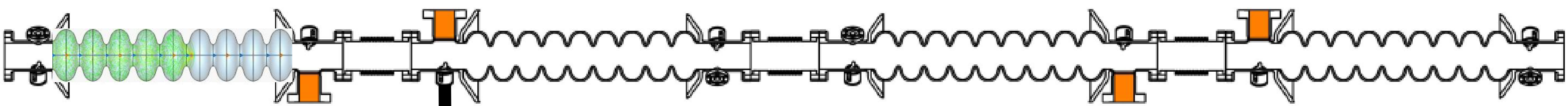
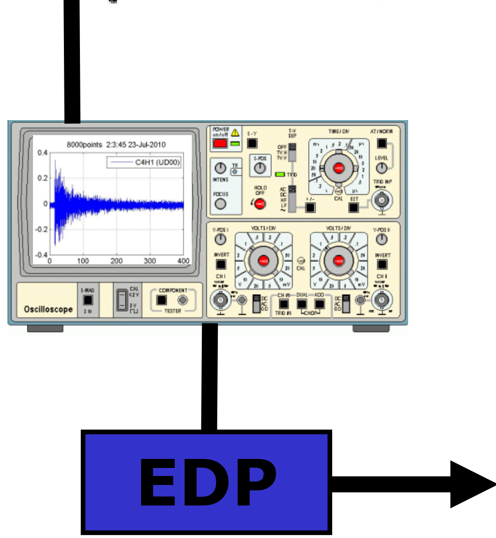
Motivation: „Parasitical“ use of HOM couplers: Diagnostic System based on HOM port signals* of ACC39 mounted in FLASH



String of cavities in ACC39**



Information about:

- Transversal momentum and offset of bunch
- Perturbances of cavity
- Total charge of bunch

*Principle according to S. Molloy et al.: “High precision superconducting cavity diagnostics with higher order mode measurements", Phys. Rev. Spec. Top. Accel. Beams 9 (2006) 112802, 2006.

**Picture taken from: E. Vogel et al.: “Status of the 3rd harmonic systems for FLASH and XFEL in summer 2008”, Proc. LINAC 2008.

Roadmap

- Evaluation of computational tools with simplified cavity/coupler geometry.
- Efficient calculation of influence of perturbations on spectra.

last talk

- S-parameter computation for ACC39 and comparison with measurements at FLASH (verification of model)
- Development of a scheme for element-wise computation of beam-induced signal at ports …
- … and superposition of signals in concatenated elements …

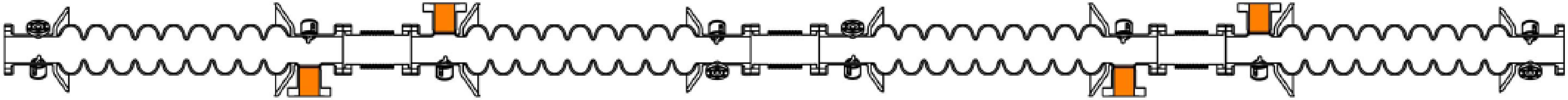
today's talk

- … to predict broadband HOM-coupler signals depending on beam and geometrical parameters.

not started yet

Modeling of Module ACC39 mounted in FLASH

- Besides experiments numerical modeling is needed to understand transient beam-excited HOM port signals.
- Is it enough to consider cavities individually or is it necessary to model the entire cavity string?
- Need to ensure that model reflects properties of system in an accurat manner.



String of cavities in ACC39*

*Picture taken from: E. Vogel et al.: "Status of the 3rd harmonic systems for FLASH and XFEL in summer 2008", Proc. LINAC 2008.

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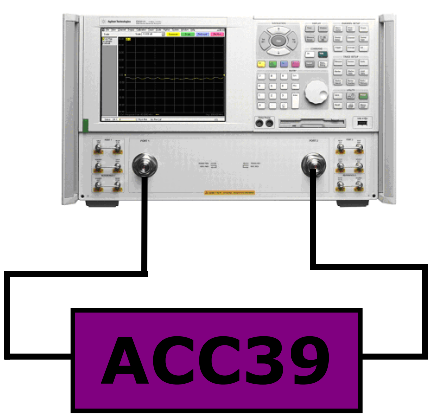
Validation of Model using S-parameters



$$\mathbf{S}_{Meas}(\omega) \overset{?}{=} \mathbf{S}_{Simul}(\omega)$$

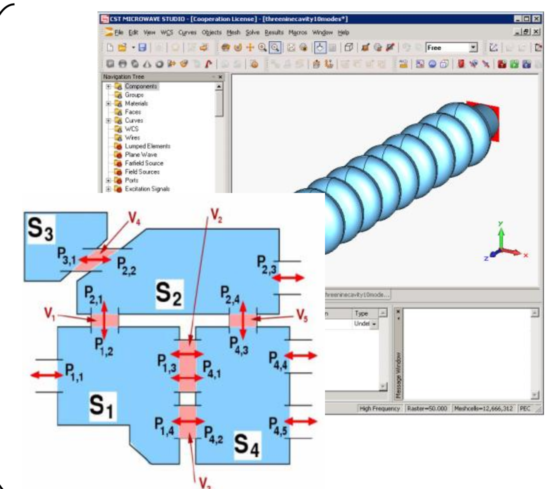


Figure courtesy of K. Rothemund

S-parameters are suitable for model validation as they can be measured and computed.

Measurement of S-parameters of ACC39

Measurement* of S-parameters

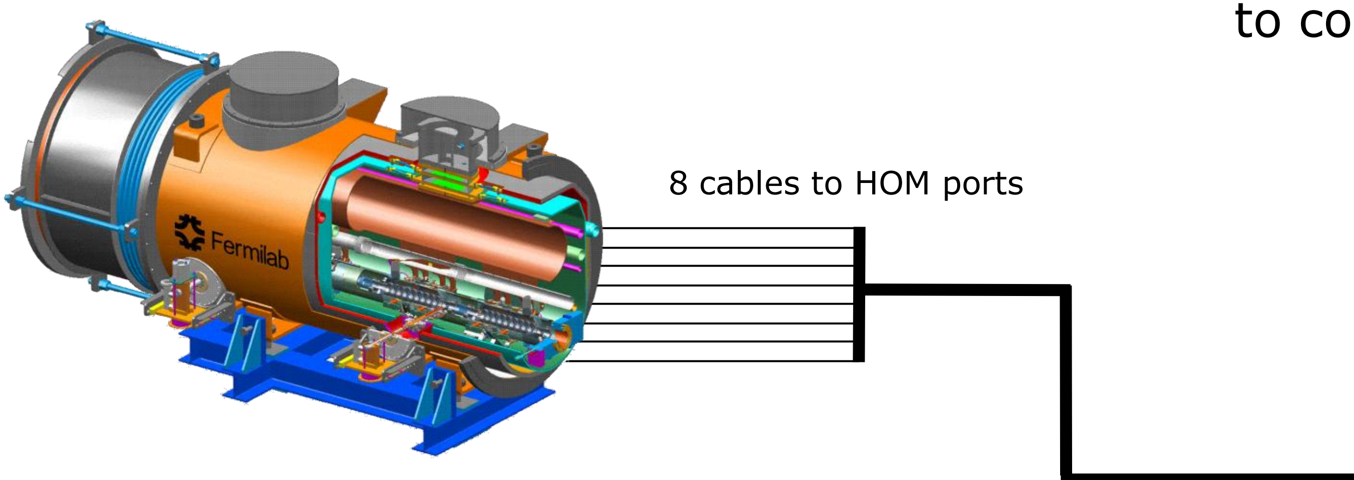
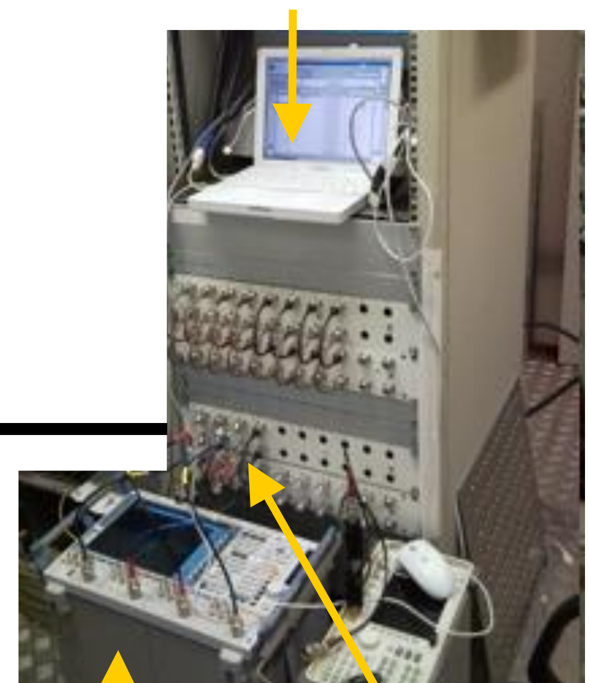


Figure courtesy of E. Vogel

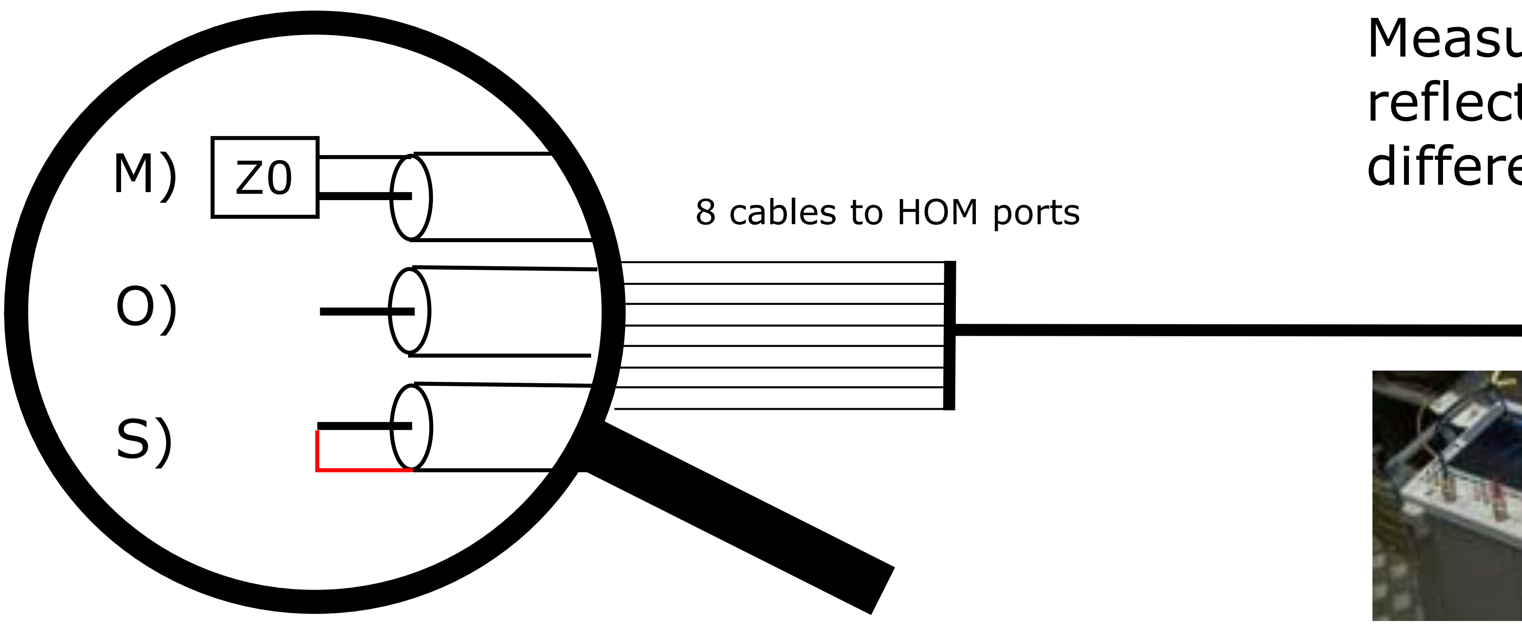


- 28 transmission and 8 reflection spectra measured
- Interval from 3.5 GHz to 8 GHz sampled with Δf=10kHz (450001 frequency samples) to capture peaks of high Q factor

*N. Baboi (DESY), T. Flisgen and H.-W. Glock (Universität Rostock), I. Shinton (University of Manchester / Cockcroft Institute), P. Zhang (University of Manchester /DESY)

One port Matched-Open-Short Calibration of Cables*

Measurements of cable reflections with three different terminations



*direct measurement of cable transmission was not possible due to their fixed installation

Measurements (total sweep time T ≈ 4 d) result in $\mathbf{S}_{ACC39,Meas} \in \mathbb{C}^{8\times 8}$ and eight matrices $\mathbf{S}_{Cable,Meas} \in \mathbb{C}^{2\times 2}$.

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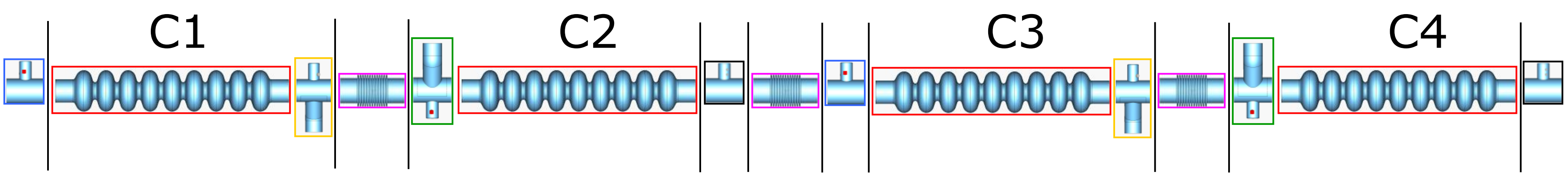
Simulation of S-parameters of ACC39

Simulation of S-parameters

- Costly to discretize entire structure, but
- ACC39 is made of identical sub-structures (cavities, HOM couplers, bellows).
- Efficient to compute scattering properties of sub-structures and to concatenate the obtained S-matrices using CSC*.
- Circular waveguides or rotations (indicated by black lines) need not to be treated numerically.



*H.-W. Glock, K. Rothemund, U. van Rienen: "CSC - A System for Coupled S-Parameter Calculations", TESLA-Report 2001-25

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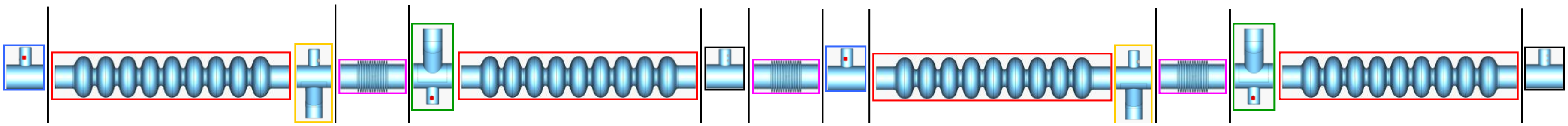
Details of ACC39 S-parameter Simulation



CSC Device	Number of mesh cells	Duration of Computation*
Cavity	12,666,312	56 h 21 min
HOM2Leg	5,873,684	11 h 34 min
HOM2LegIC	12,999,168	15 h 53 min
HOM1Leg	5,482,620	17 h 13 min
HOM1LegIC	12,751,200	22 h 58 min
Bellow	3,413,800	6 h 22 min

*S-parameter computed in the frequency interval from 3.5 GHz to 8 GHz sampled with Δf=0.45 MHz (10001 frequency samples) using CST‘s Resonant Fast S-parameter Module

Considered pipe modes for expansion:

1. TE11 Pol. 1 fco = 4.3920 GHz
2. TE11 Pol. 2 fco = 4.3920 GHz
3. TM01 fco = 5.7371 GHz
4. TE21 Pol. 1 fco = 7.2858 GHz
5. TE21 Pol. 2 fco = 7.2858 GHz
6. TE01 fco = 9.1412 GHz
7. TM11 Pol. 1 fco = 9.1412 GHz
8. TM11 Pol. 2 fco = 9.1412 GHz
9. TE31 Pol. 1 fco = 10.022 GHz
10. TE31 Pol. 2 fco = 10.022 GHz

CSC coupling (T ≈ 10 min) results in $\mathbf{S}_{ACC39,Simul} \in \mathbb{C}^{32\times 32}$

Comparison between Measurement and Simulation

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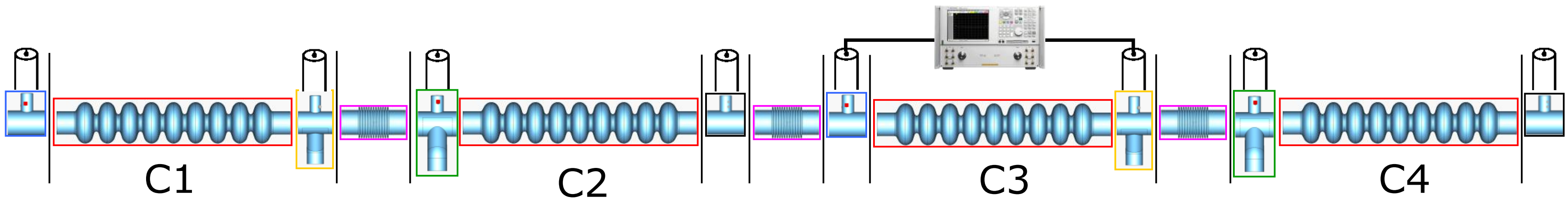
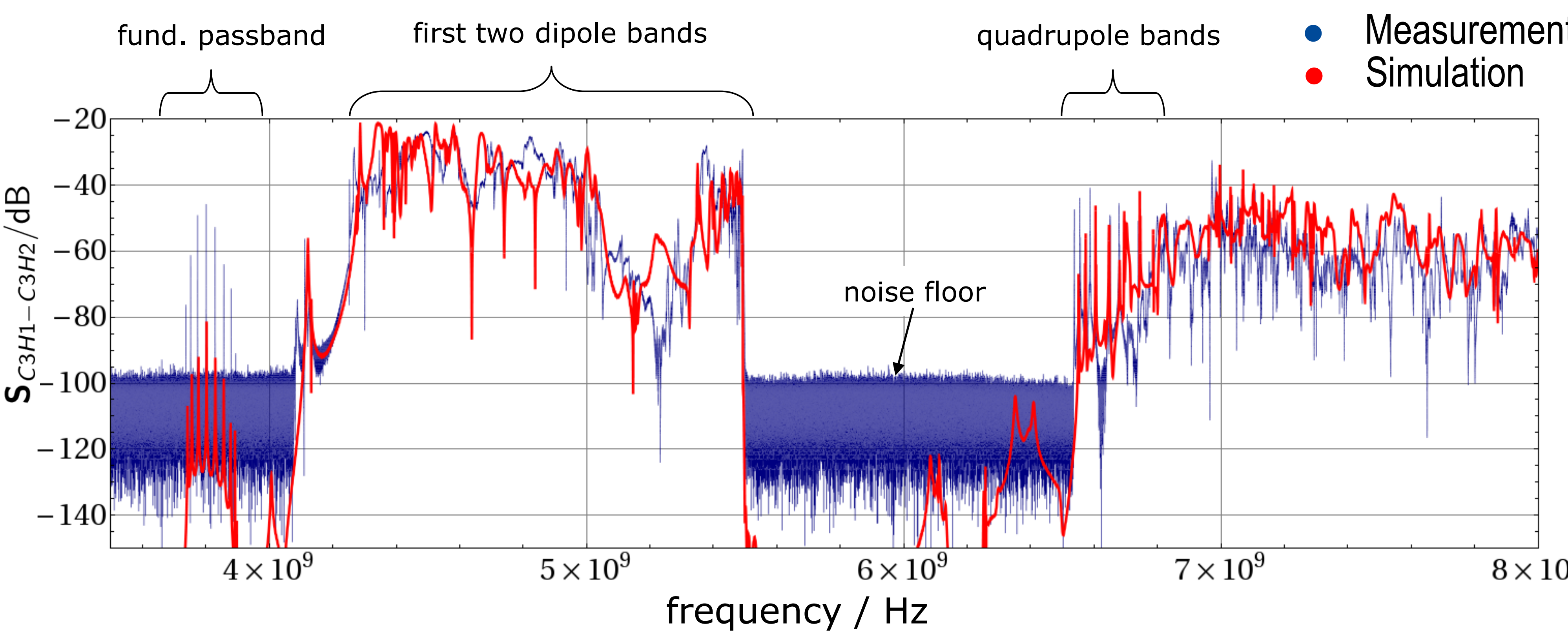
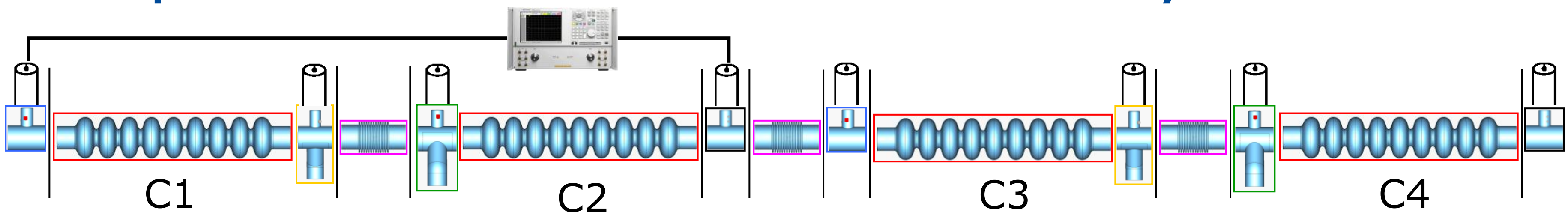
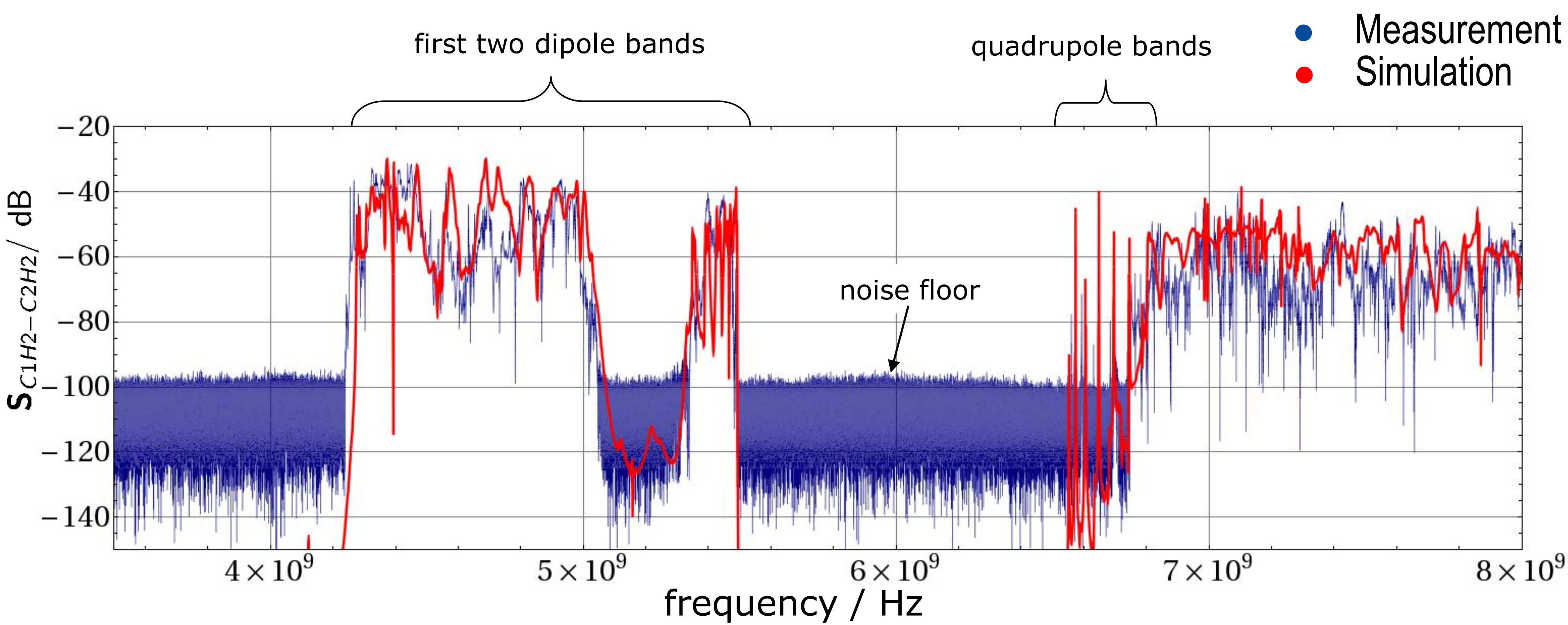
Example I: Transmission via Cavity 3



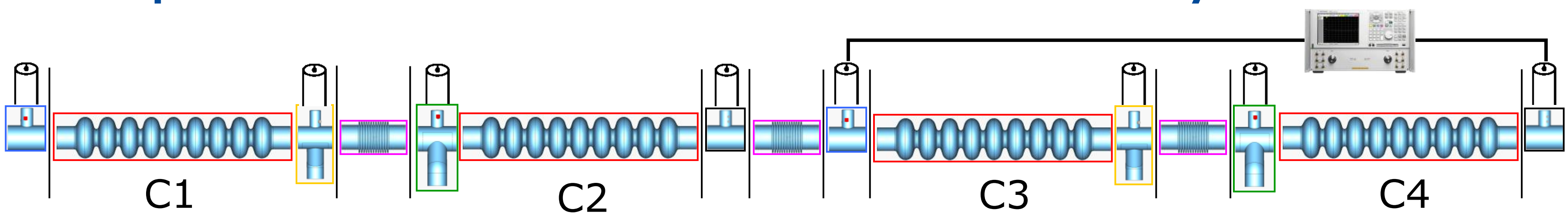


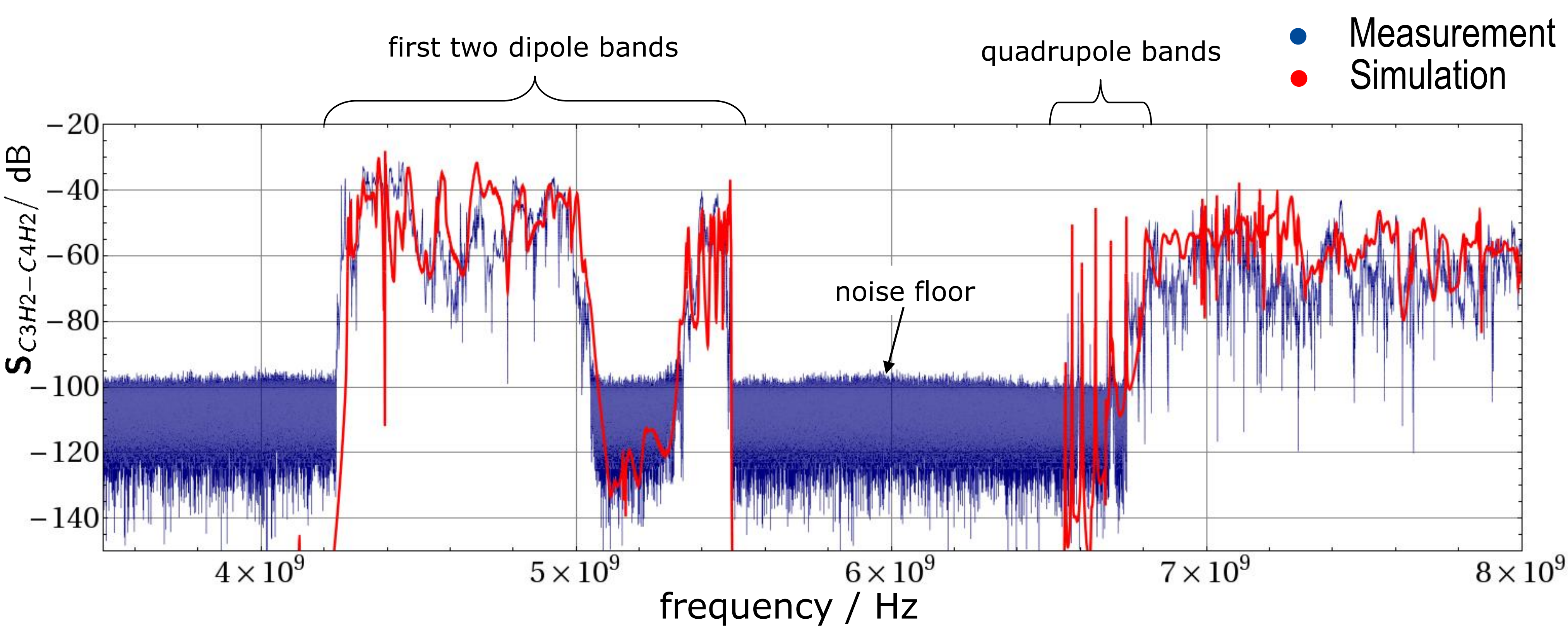
Example II: Transmission via Cavity 1 and 2





Example III: Transmission via Cavity 3 and 4





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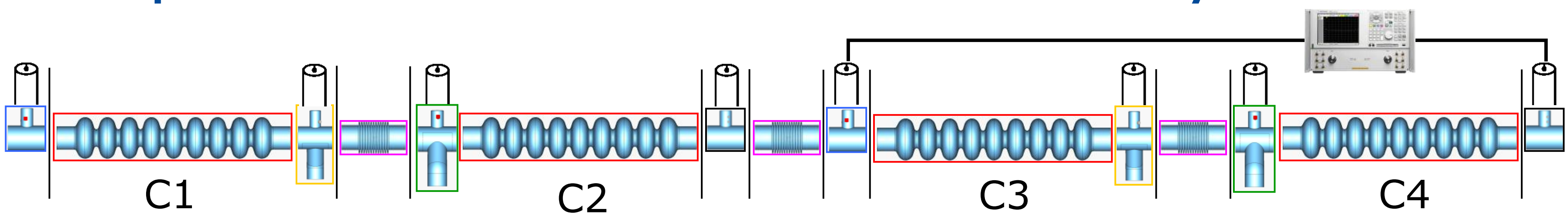
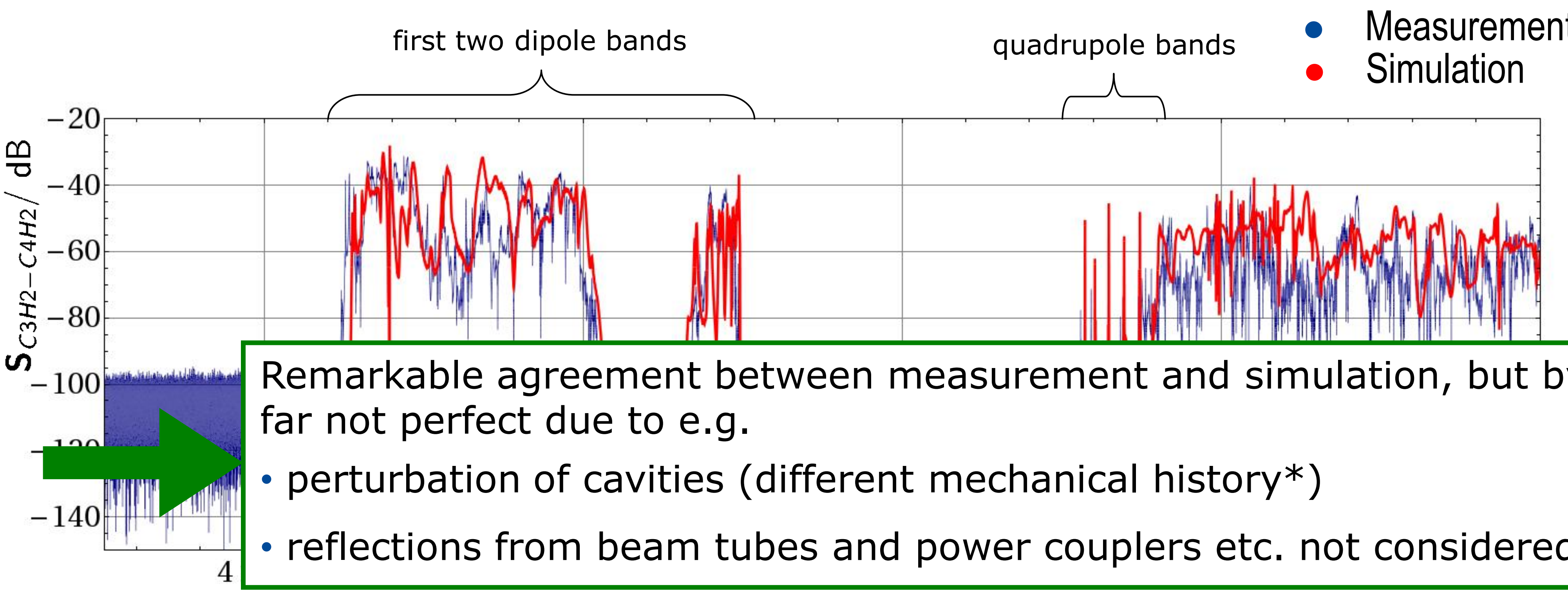
Example III: Transmission via Cavity 3 and 4





Remarkable agreement between measurement and simulation, but by far not perfect due to e.g.

- perturbation of cavities (different mechanical history*)
- reflections from beam tubes and power couplers etc. not considered

* T. Khabiboulline, personal communication, Oct. 2010

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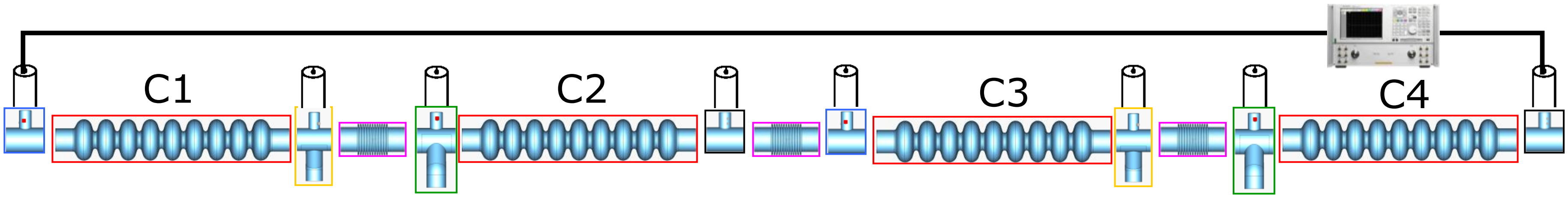
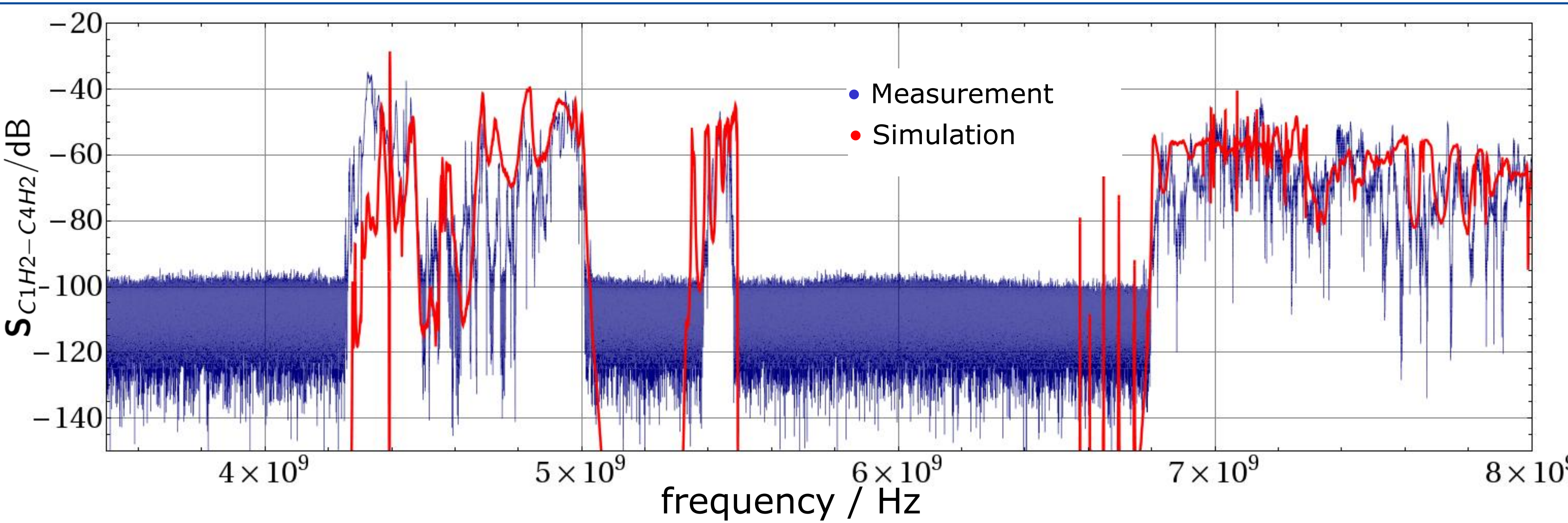
Example IV: Transmission via entire String





Need to consider the whole string instead of individual cavities since HOMs can propagate through entire string

… but still beam is not considered…

Simulation of Beam Excited Port Signals for ACC39

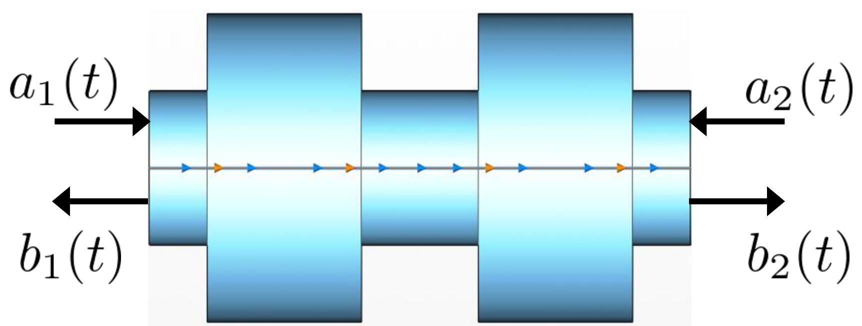
- Costly to discretize entire structure for wakefield computation, but
- ACC39 is made of identical sub-structures (cavity, HOM couplers, bellows).
- Efficient to compute (HOM) port signal contributions of sub-structures and concatenate those using methods similar to CSC.
- Sections with constant cross section do not have to be treated numerically and they do not contribute to HOM port signal (if lossless).

→ Need to derive a formalism which allows an elementwise computation of beam excitation followed by coupling of elements.

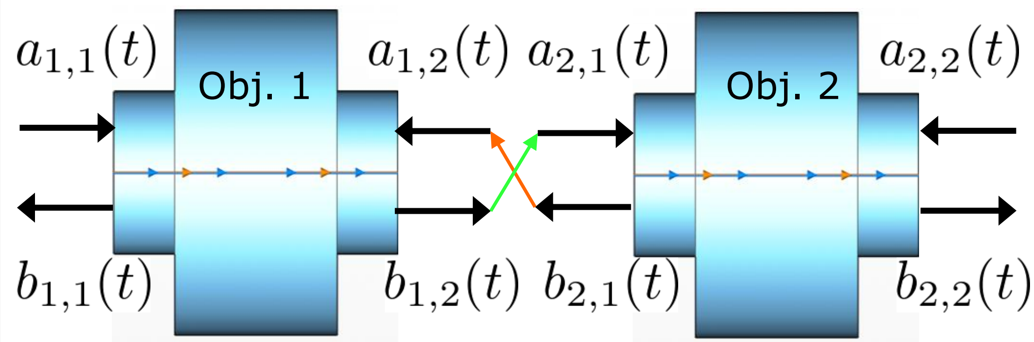
In development:
A coupling scheme for computation of beam excited HOM Signals based on CSC
-
Coupled Time Domain Computations (CTC)

Decomposition of Structure and Concatenation

Direct computation of transient beam excited port signals* using CST Particle Studio



Elementwise computation of transient beam excited port signals* using CST Particle Studio



CTC

?

$$b_1(t) = b_{1,1}(t)$$

$$b_2(t) = b_{2,2}(t)$$

*scattered in TM01 mode

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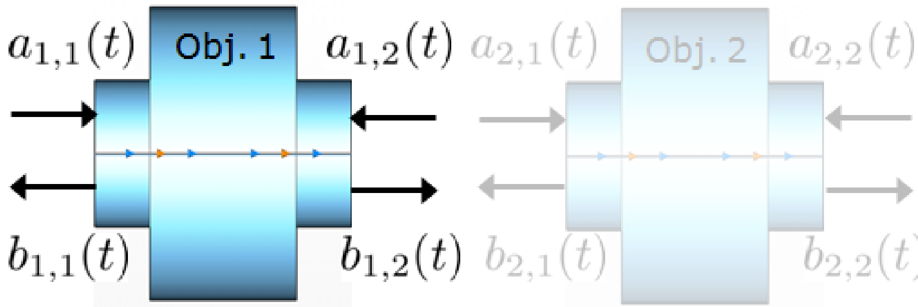
Scattered Signals in Ports of Substructure with Beam



For sufficiently stiff beam* scattered signals are superpositions of internal sources (beam excited fields) and incident signals at ports of substructure:

incident transient signals at ports of object 1

$$\begin{pmatrix} b_{1,1}(t) \\ b_{1,2}(t) \end{pmatrix} = \begin{pmatrix} s_{1,11}(t) & s_{1,12}(t) \\ s_{1,21}(t) & s_{1,22}(t) \end{pmatrix} * \begin{pmatrix} a_{1,1}(t) \\ a_{1,2}(t) \end{pmatrix} + \begin{pmatrix} y_{1,1}(t) \\ y_{1,2}(t) \end{pmatrix}$$

scattered transient signals at ports of object 1

impulse responses of object 1 (not known in general)

convolution operator

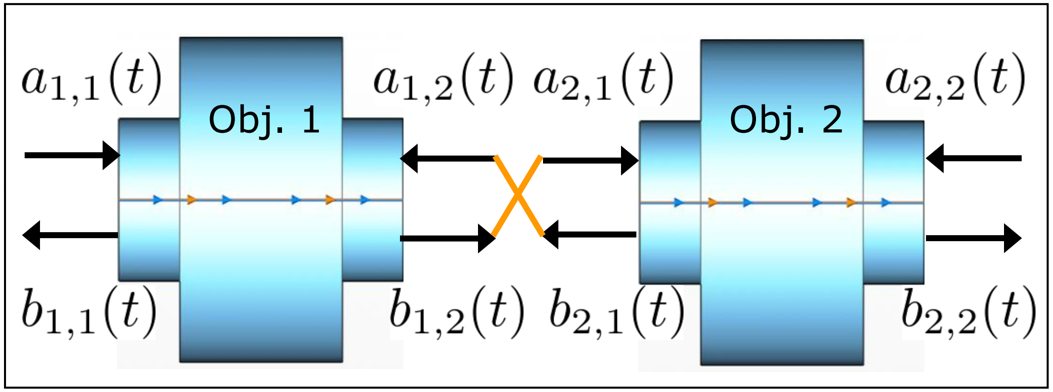
transient signal excited by beam scattered in ports of object 1 (computed with CST Particle Studio®)

*field equations and equations of motion are decoupled

Coupling of two Elements

$$\begin{pmatrix} b_{1,1}(t) \\ b_{1,2}(t) \end{pmatrix} = \begin{pmatrix} s_{1,11}(t) & s_{1,12}(t) \\ s_{1,21}(t) & s_{1,22}(t) \end{pmatrix} * \begin{pmatrix} a_{1,1}(t) \\ a_{1,2}(t) \end{pmatrix} + \begin{pmatrix} y_{1,1}(t) \\ y_{1,2}(t) \end{pmatrix}$$

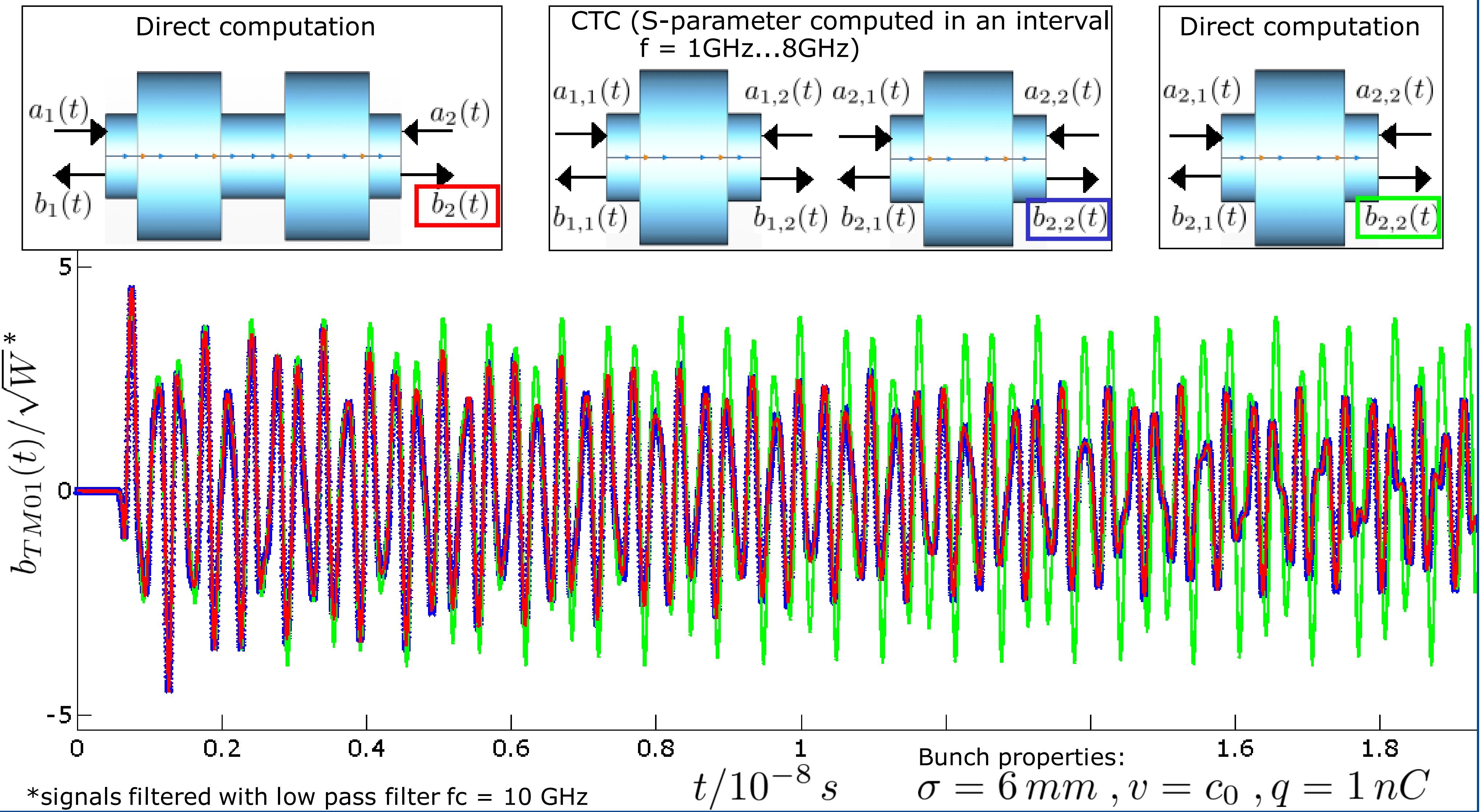
$$\begin{pmatrix} b_{2,1}(t) \\ b_{2,2}(t) \end{pmatrix} = \begin{pmatrix} s_{2,11}(t) & s_{2,12}(t) \\ s_{2,21}(t) & s_{2,22}(t) \end{pmatrix} * \begin{pmatrix} a_{2,1}(t) \\ a_{2,2}(t) \end{pmatrix} + \begin{pmatrix} y_{2,1}(t) \\ y_{2,2}(t) \end{pmatrix}$$



Plugging these equations together with topology information into CSC

$$\begin{pmatrix} b_{1,1}(t) \\ b_{2,2}(t) \end{pmatrix} = \underbrace{\begin{pmatrix} s_{csc,11}(t) & s_{csc,12}(t) \\ s_{csc,21}(t) & s_{csc,22}(t) \end{pmatrix}}_{\mathbf{S}_{csc}(t) = f(\mathbf{S}_1(t), \mathbf{S}_2(t))} * \begin{pmatrix} a_{1,1}(t) \\ a_{2,2}(t) \end{pmatrix} + \underbrace{\begin{pmatrix} m_{11}(t) & m_{12}(t) \\ m_{21}(t) & m_{22}(t) \end{pmatrix}}_{\mathbf{M}_{beam}(t) = g(\mathbf{S}_1(t), \mathbf{S}_2(t))} * \begin{pmatrix} y_{1,2}(t) \\ y_{2,1}(t) \end{pmatrix} + \begin{pmatrix} y_{1,1}(t) \\ y_{i,2}(t) \end{pmatrix}$$

CTC - Proof of Principle



Bunch properties:
$\sigma = 6\,mm\,,v = c_0\,,q = 1\,nC$

*signals filtered with low pass filter fc = 10 GHz

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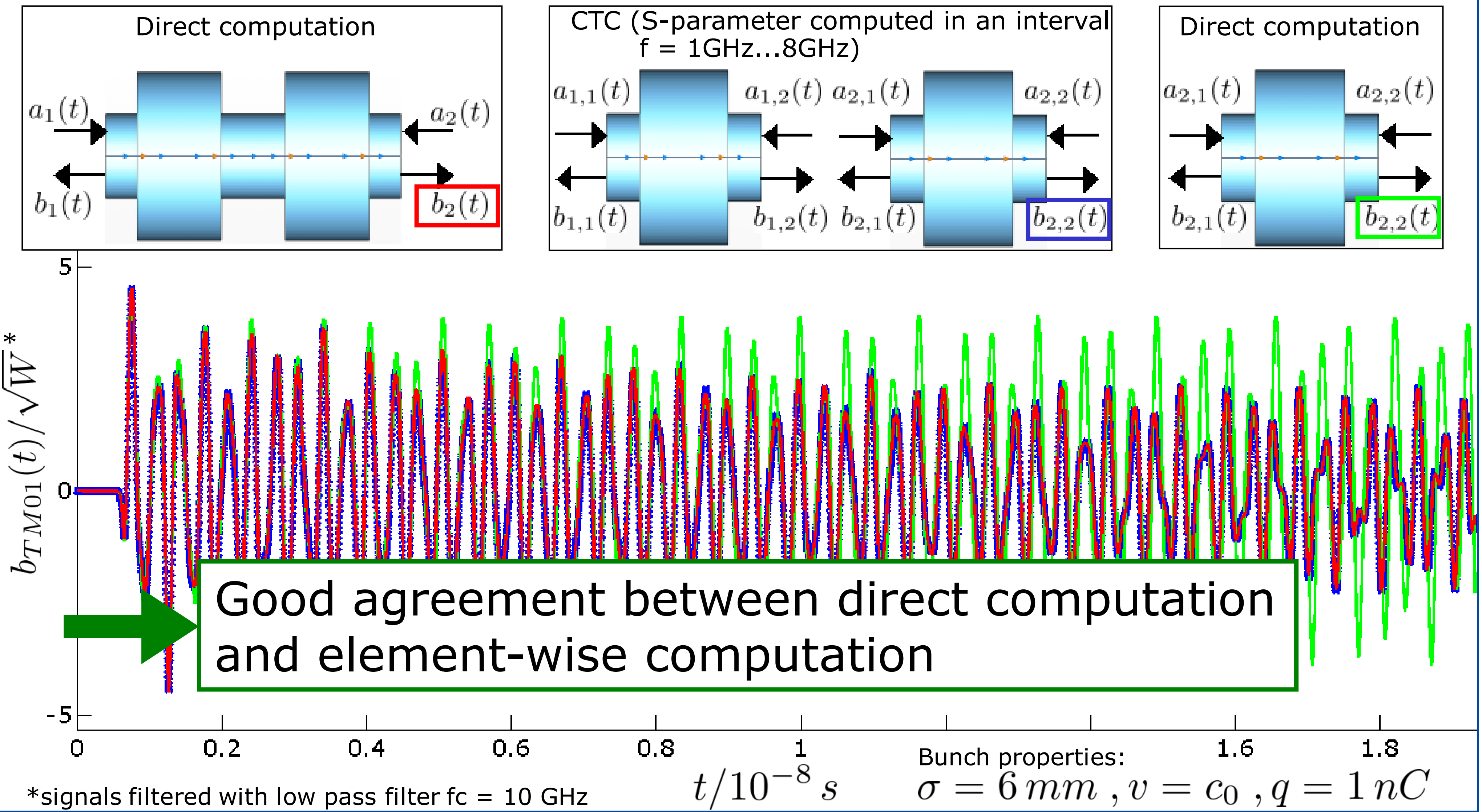
CTC - Proof of Principle



Good agreement between direct computation and element-wise computation

Bunch properties:
$\sigma = 6\,mm$, $v = c_0$, $q = 1\,nC$

*signals filtered with low pass filter fc = 10 GHz

HOM Signal Detection using Diode

HOM signal detection using diode downmixing scheme

- Not EuCARD, but BMBF-funded (contract 05K10HRC), …
- ..., but closely related.

- Concept: Avoid local oscillator ...
- ... by enforcing self-mixing of HOM signal components …
- ... at an RF-detector diode.

- Detection in time domain, …
- ..., extraction of dominant signal contributions using SingularValueDecomposition, ...
- ... and least-square fitting to BPM-readouts assuming a linear correlation.

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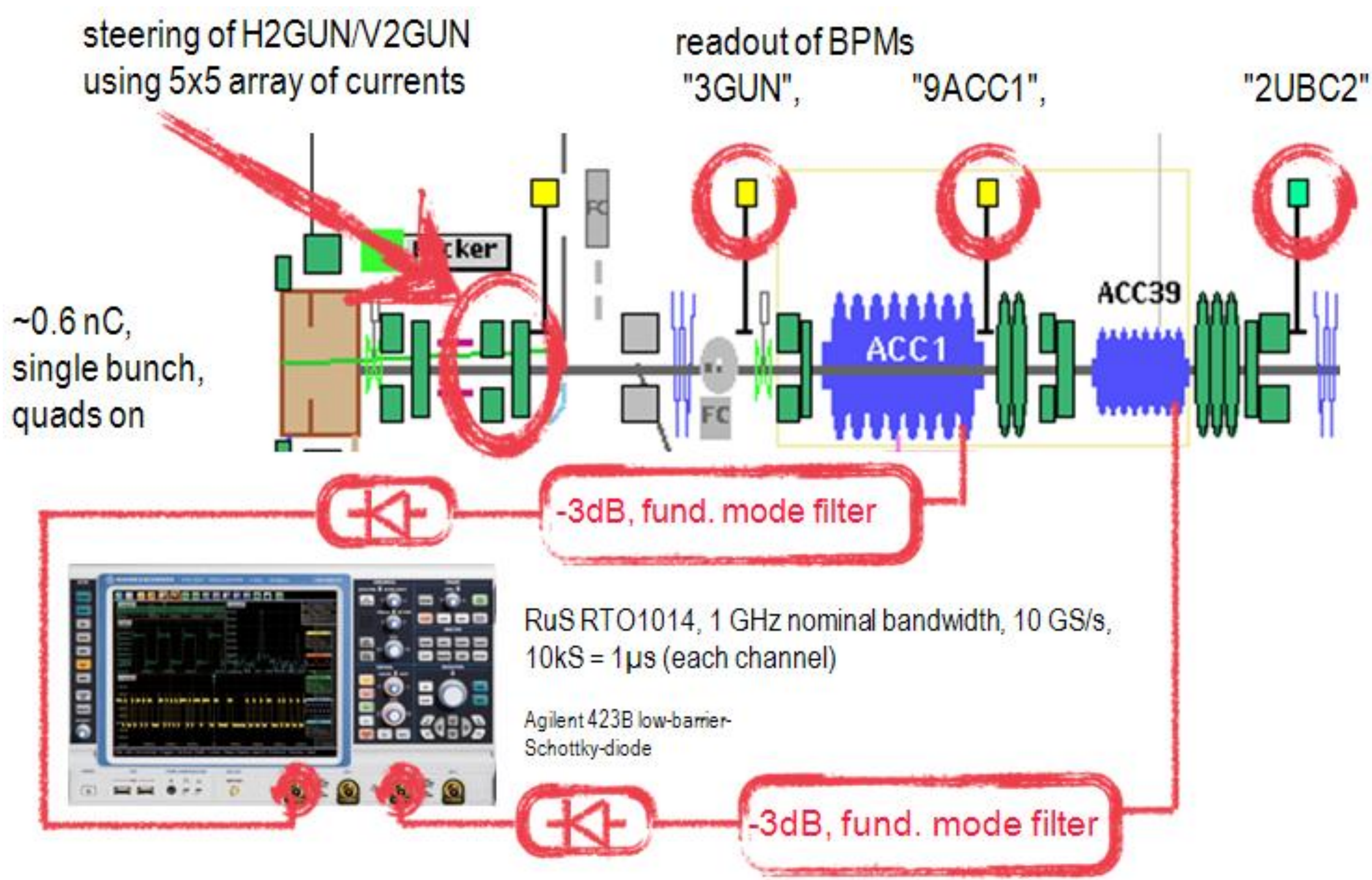
Taking in parallel signals from ACC1-C8H1 und ACC39-C4H2



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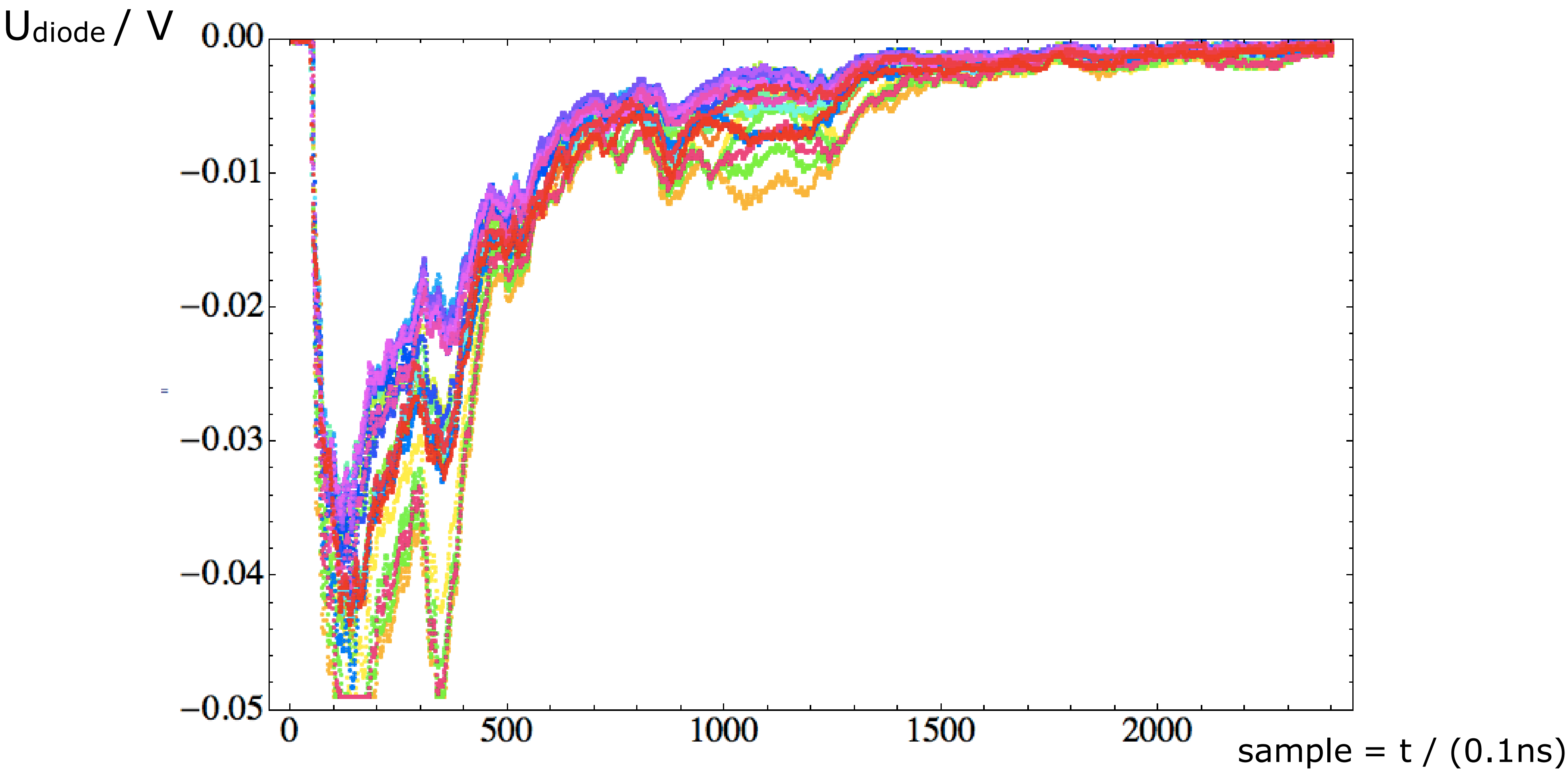
ACC39: All 24* (+1) raw diode voltage signals vs. time**



*: one position accidentally not stored
**: signal clipped in time covering only "interesting" range = 2400 samples = 0.24 µs

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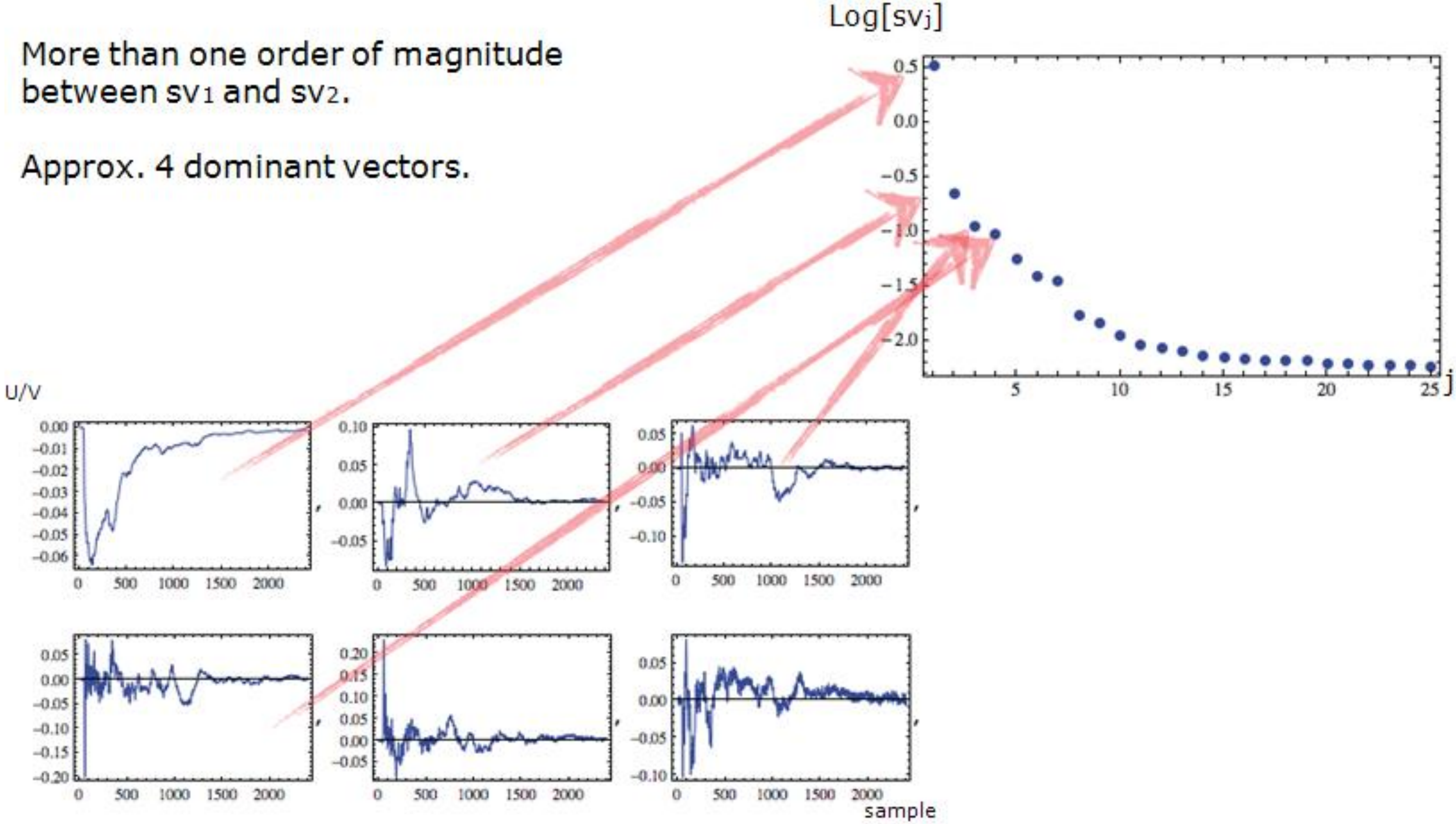
SVD basis vectors and weights for ACC39 signals

More than one order of magnitude between sv_1 and sv_2.

Approx. 4 dominant vectors.



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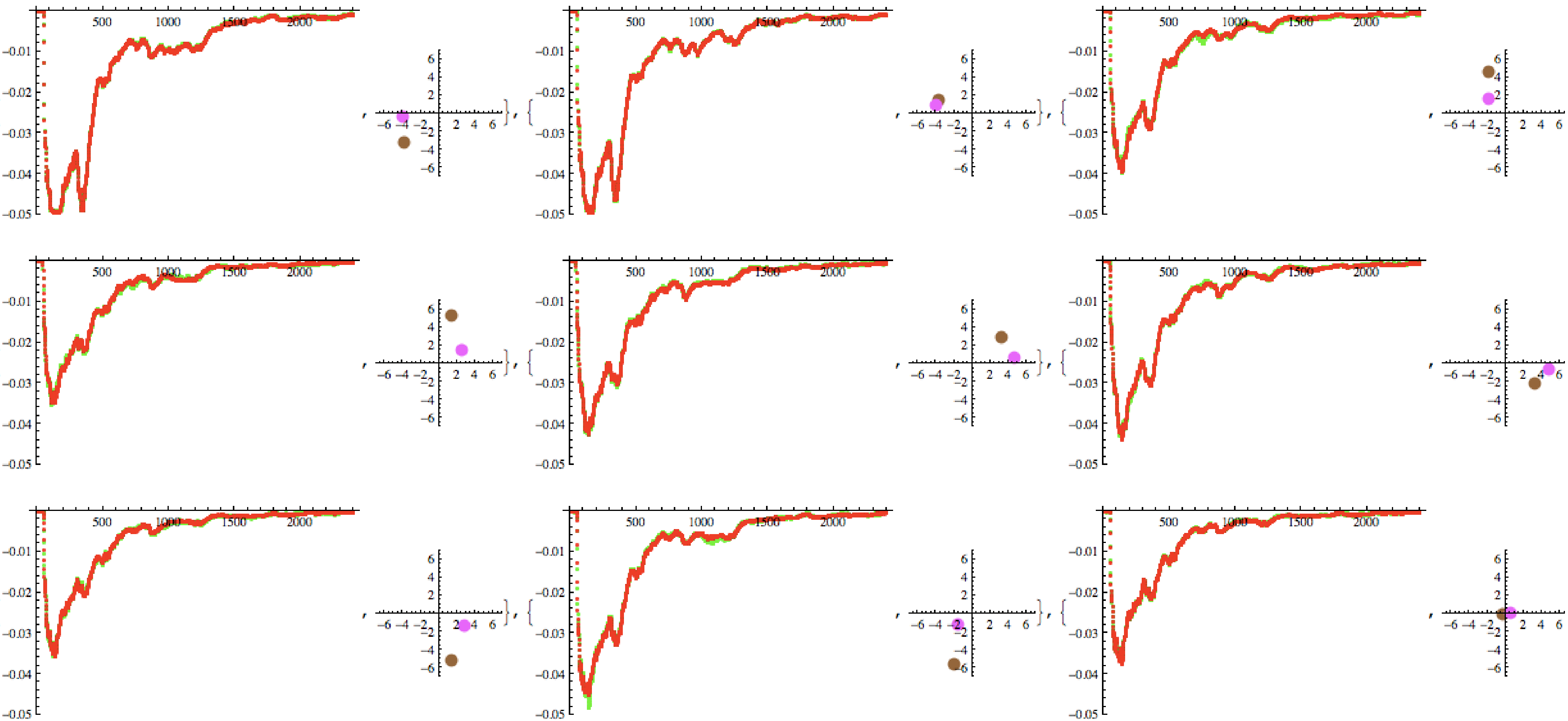
Check SVD for ACC39 signals (shown 9 of 25)

all graphs U/V vs. time sample



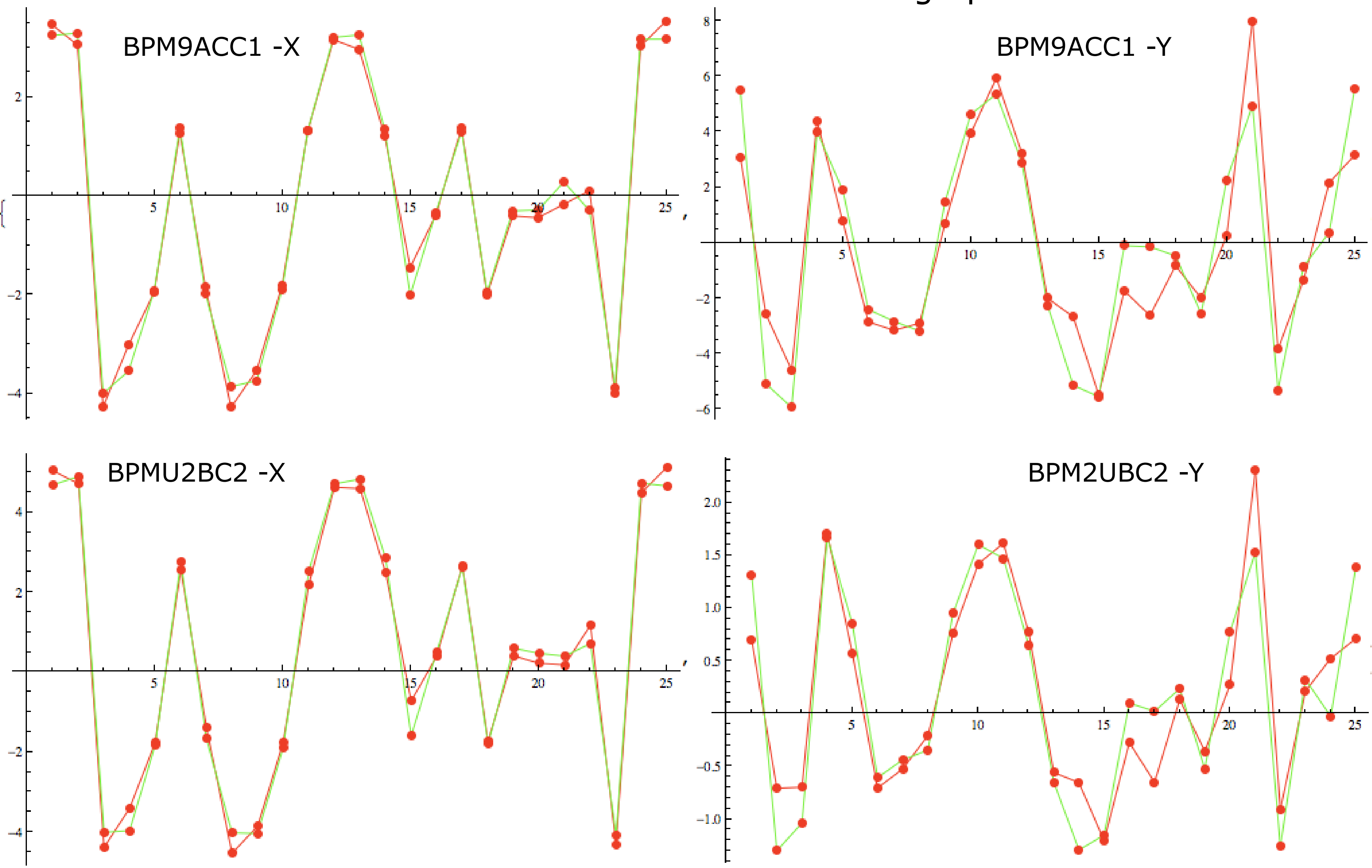
green: original - (almost impossible to see)
red: reconstructed out of **4 first svd basis vectors**

magenta: BPM 2UBC2/mm
brown: BPM 9ACC1/mm

ACC39: svd-vecs 2-5 and using an bpm/signal offset

Measurement (green connection) vs. prediction (red)

all graphs mm vs. steerer configuration index



Conclusion Diode-based HOM Measurements (after 6 month)

- HOM signal downmixing with detector diodes ...
- ... together with SVD decomposition scheme ...
- ... delivers a set of quantities in dominantly linear correlation to BPM readouts ...
- ... even without a distinct mode spectrum (-> ACC39).
- Promising start for continued analysis of most appropriate evaluation schemes in order to estimate resolution capabilities.

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Summary and Future Plans

Summary

- Comparison between measurement and simulation of S-parameter of ACC39 shown
- Motivation for development of coupling strategies for beam-excited HOM port signals presented
- Description of idea using simple resonator (two pillboxes)
- Validity of CTC shown for simple structure
- Diode-based measurements for HOM port signals

Future Plans

- Computation of beam induced signals for entire string with various beam parameters and geometrical perturbances
- Evaluation of usability of HOM port signals for diagnostic purposes