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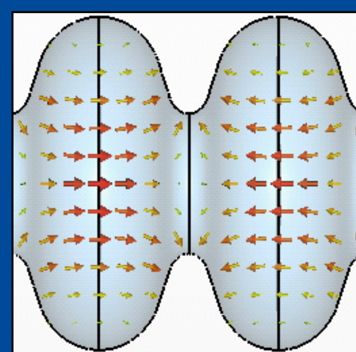

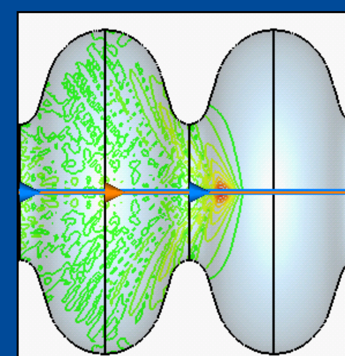

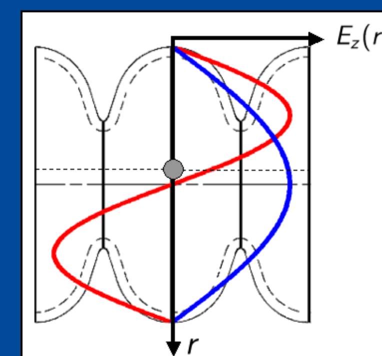

A Coupling Formalism for the Computation of Beam Excited HOM Port Signals*

Thomas Flisgen, Hans-Walter Glock and Ursula van Rienen

RFTech 3nd workshop
IBZ Rostock, 12th of December 2011

*funded by EU FP7 Research Infrastructure Grant No. 227579

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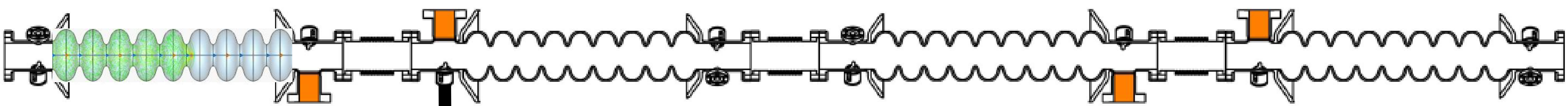
Outline

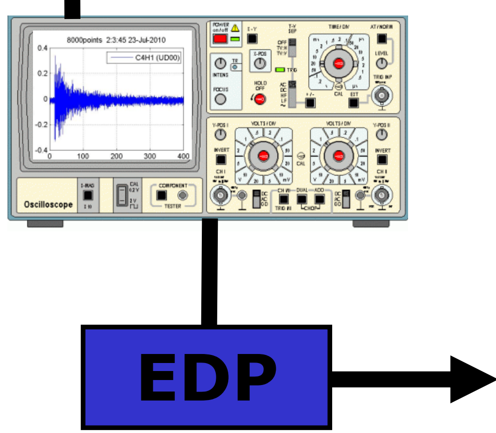
- General motivation
- Measurement and simulation of S-parameters of ACC39
- Coupling scheme for computation of beam excited HOM signals
- Measurement of beam excited HOM signals using diode downmixing scheme
- Summary and future plans

Motivation

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



String of cavities in ACC39**



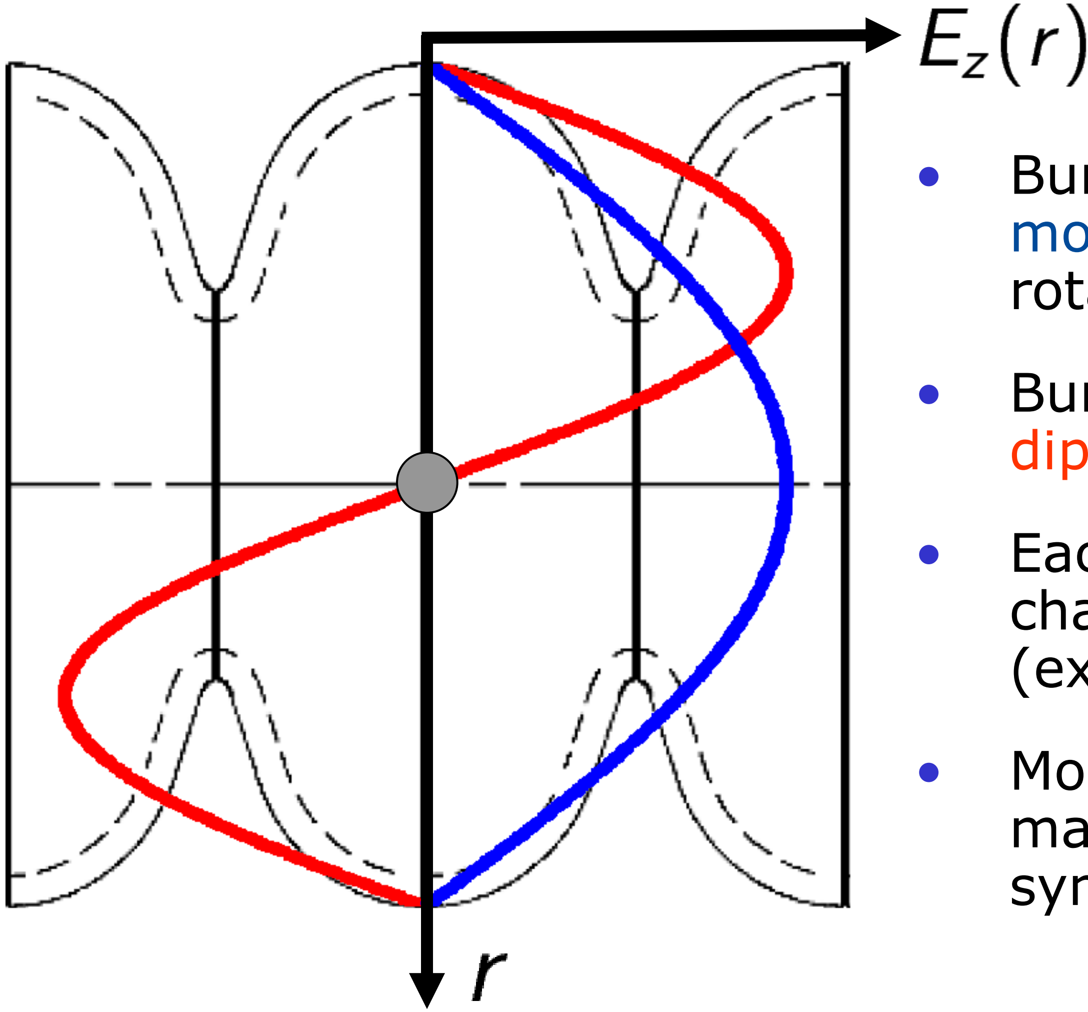
Information about:

- 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.

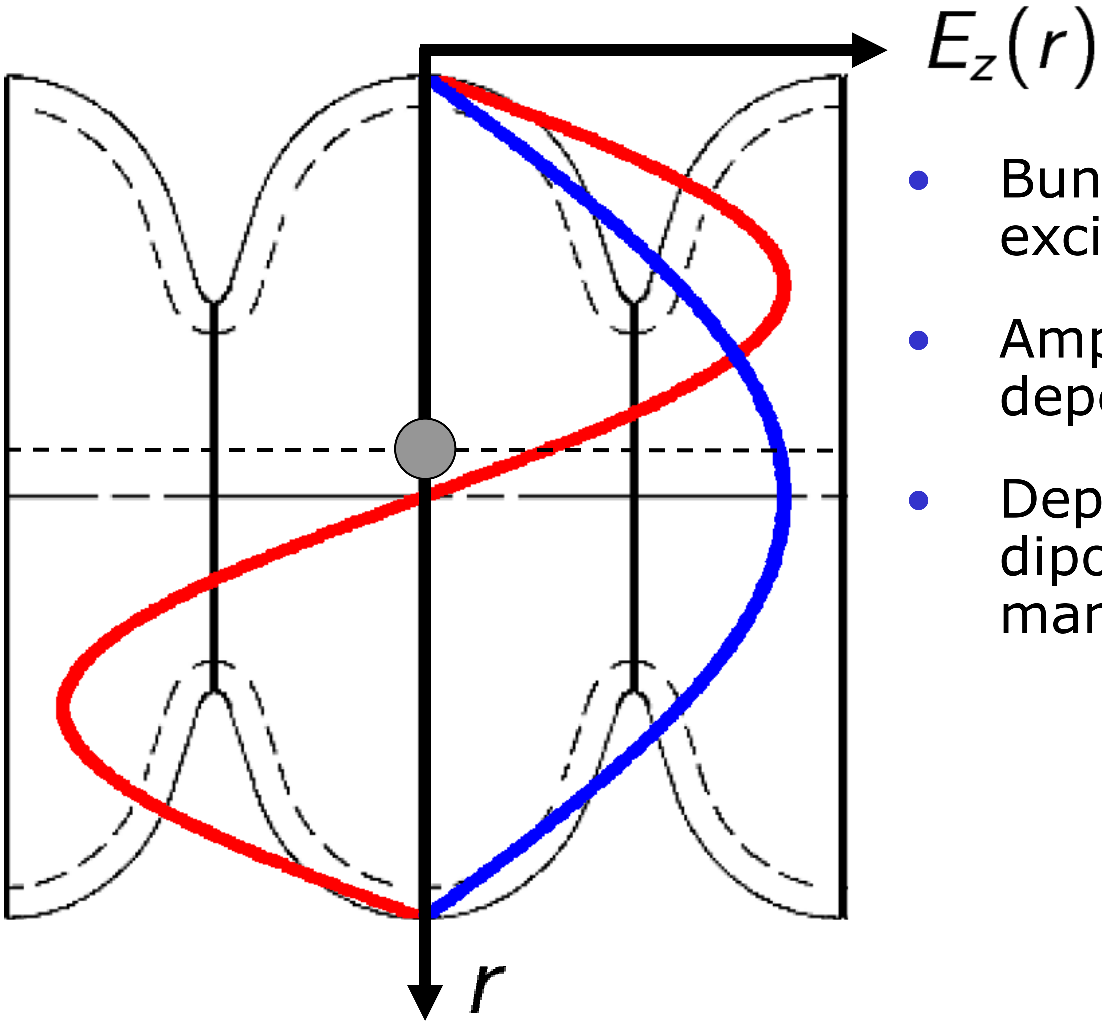
**Picture taken from: E. Vogel et al.: "Status of the 3rd harmonic systems for FLASH and XFEL in summer 2008", Proc. LINAC 2008.

Interaction of on-axis Bunch and Modes



- Bunch on axis only excites monopole modes (in case of rotational symmetry).
- Bunch cannot excite excite dipole modes.
- Each mode has its characteristic frequency (except degenerated modes).
- Modes couple in a different manner to the rotational symmetry breaking HOM port.

Interaction of off-axis Bunch and Modes



- Bunch with transversal offset excites dipole modes.
- Amplitude of dipole modes depends on offset of the bunch.
- Depending on their polarization dipole modes couple in a different manner to the HOM port.

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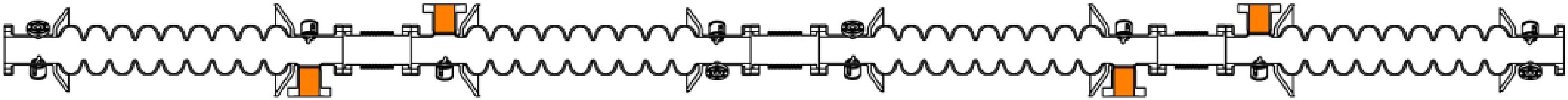
Modeling of Module ACC39 mounted in FLASH

- 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 accurate 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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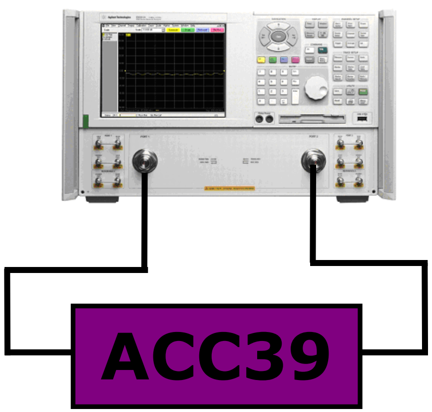
Validation of Model using S-parameters



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

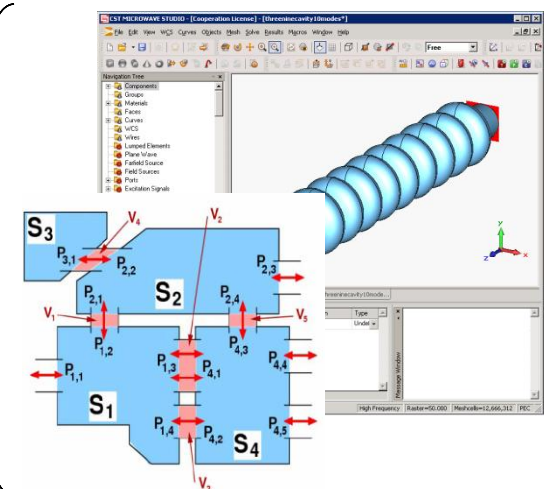


Figure courtesy of K. Rothemund

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

Measurement of S-parameters of ACC39

Measurement* of S-parameters

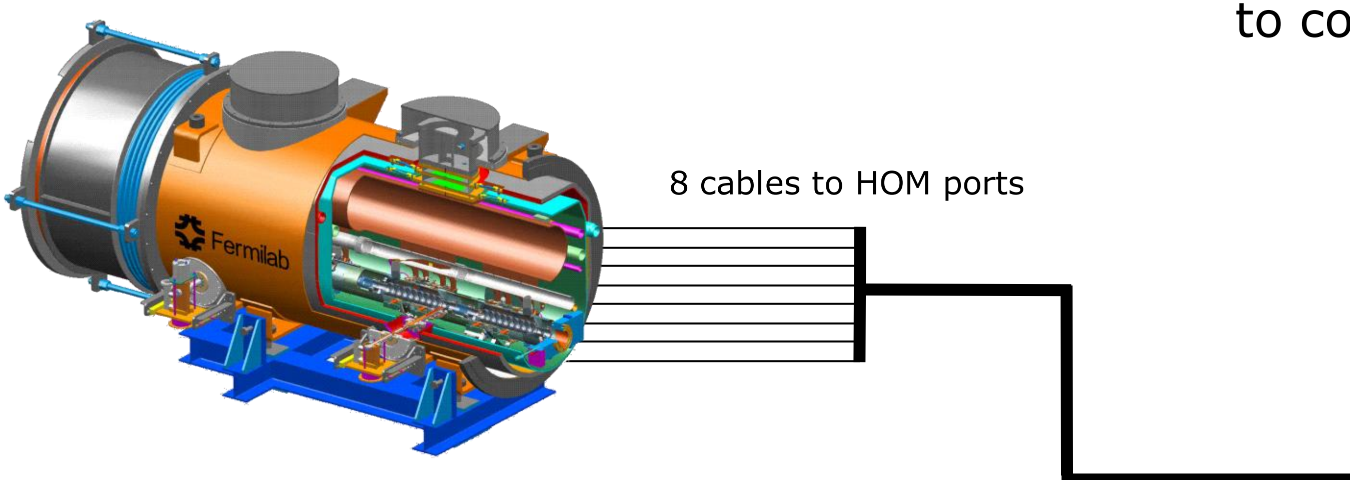
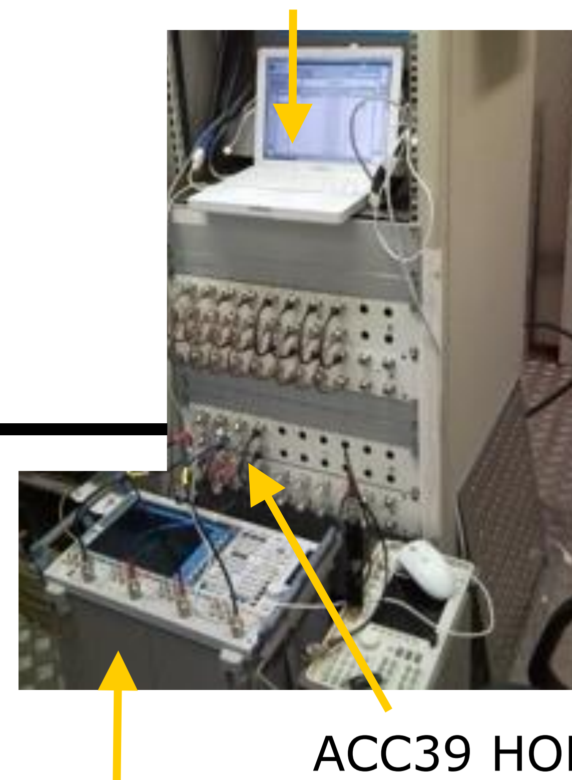


Figure courtesy of E. Vogel

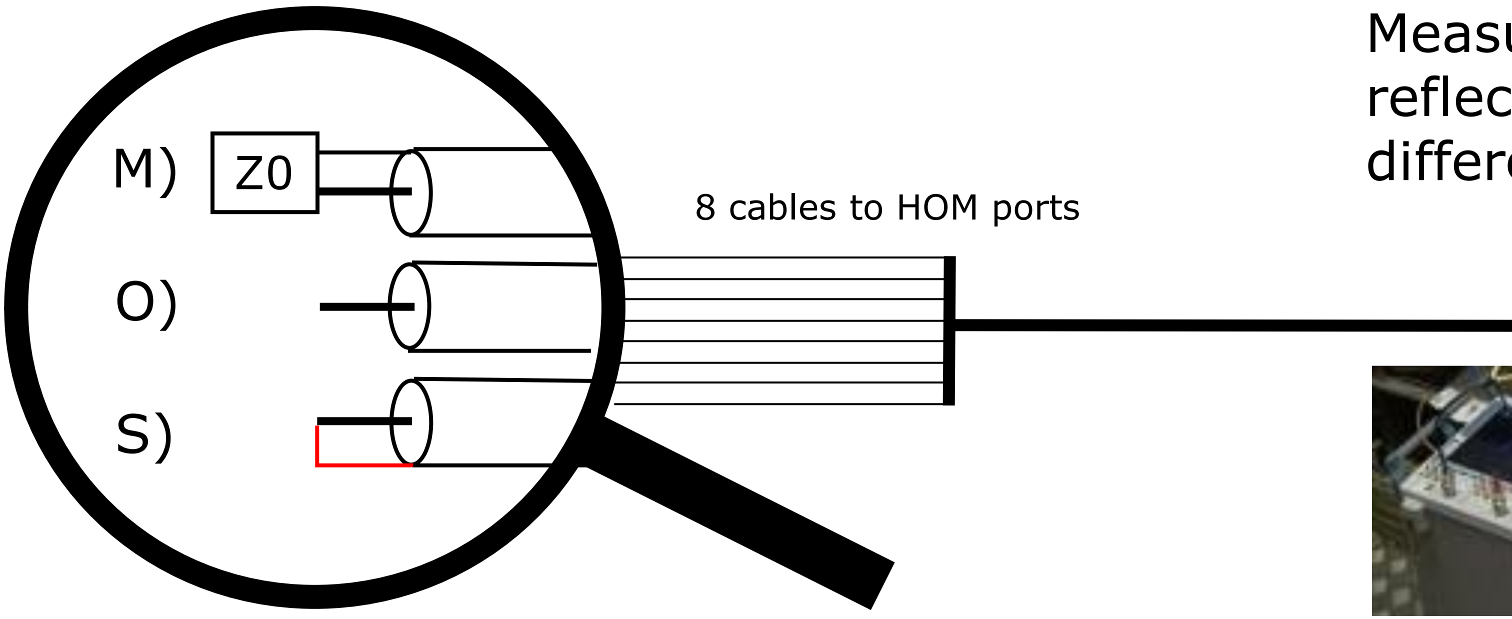


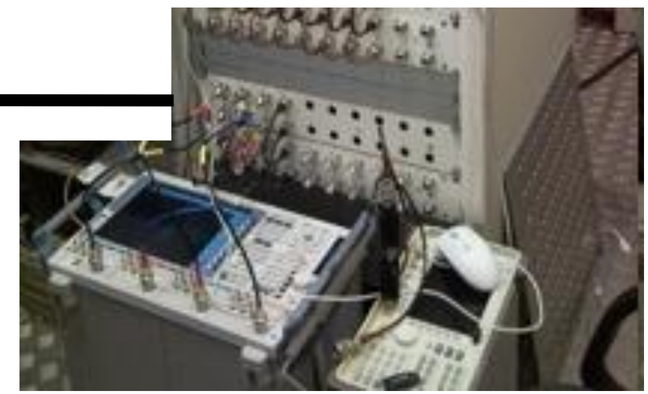
- 28 transmission and 8 reflection spectra measured
- Interval from 3.5 GHz to 8 GHz sampled with Δf=10kHz (450,001 frequency samples) to capture peaks of high Q factor

*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 $\mathbf{S}_{Cable,Meas} \in \mathbb{C}^{2\times 2}$.

Simulation of S-parameters of ACC39

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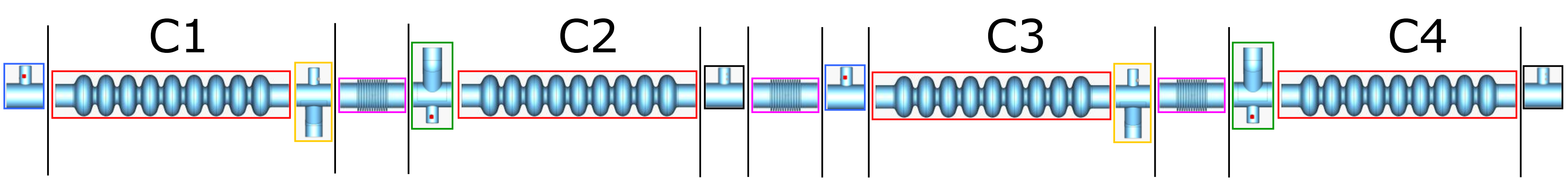
Simulation of S-Parameters

- Expensive to discretize entire structure, yet
- 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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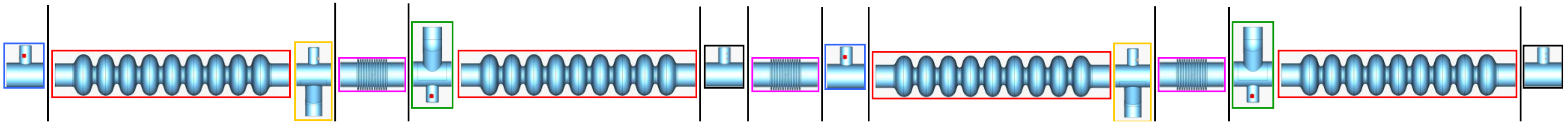
Details of ACC39 S-parameter Simulation



CSC Device	Number of mesh cells	CPU Time*
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-parameters computed in the frequency interval from 3.5 GHz to 8 GHz sampled with Δf=0.45 MHz (10,001 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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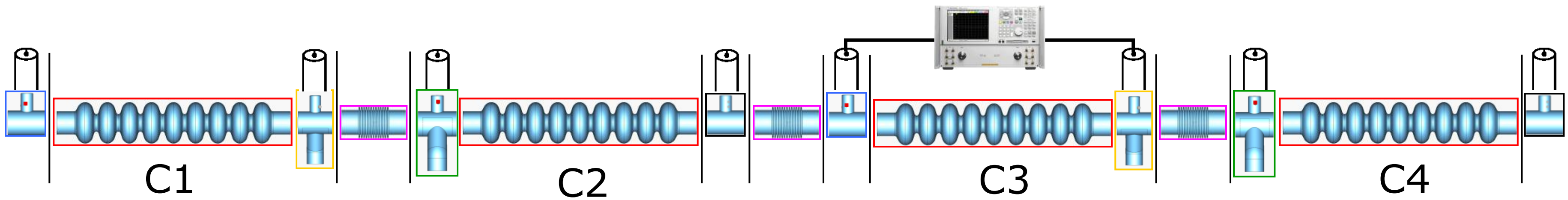
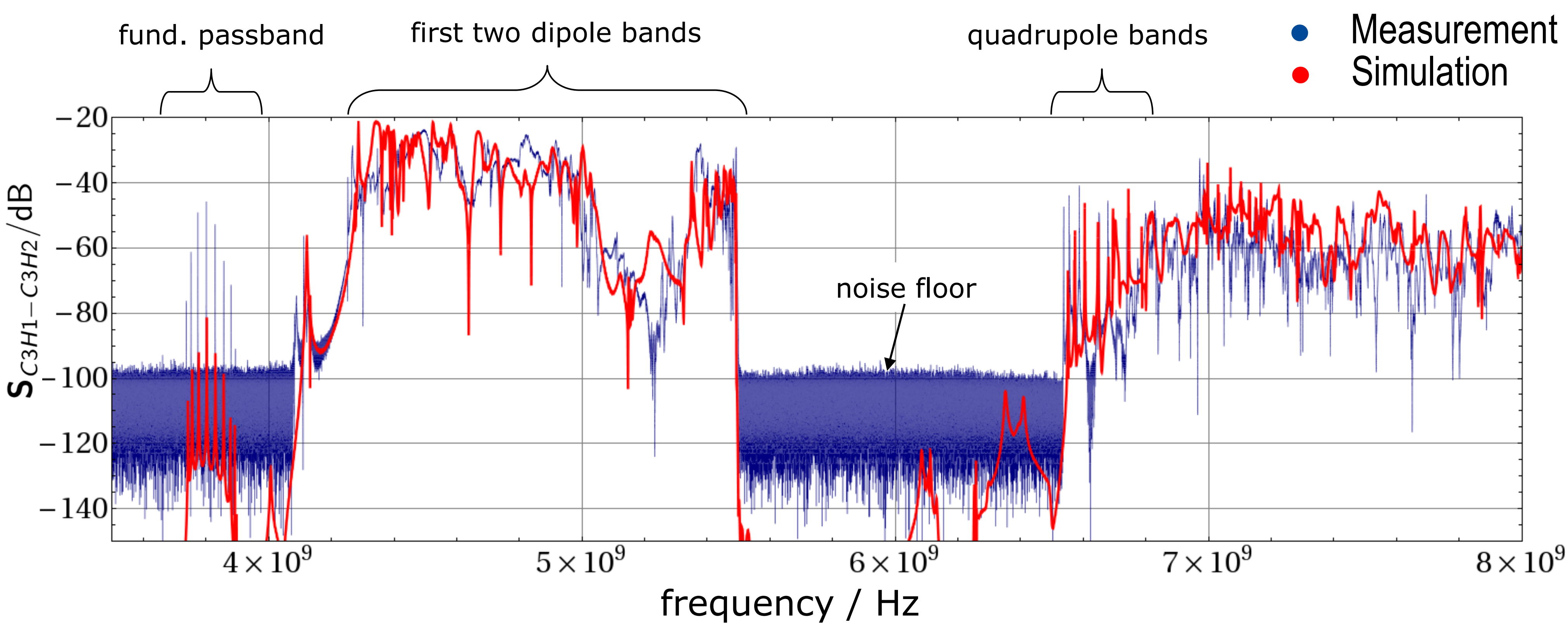
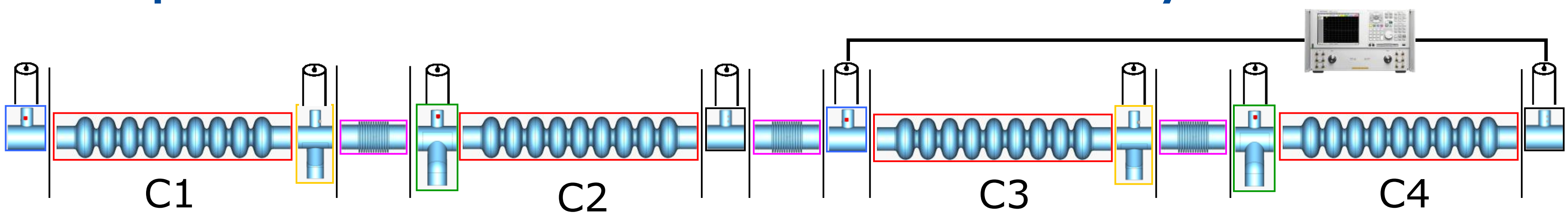
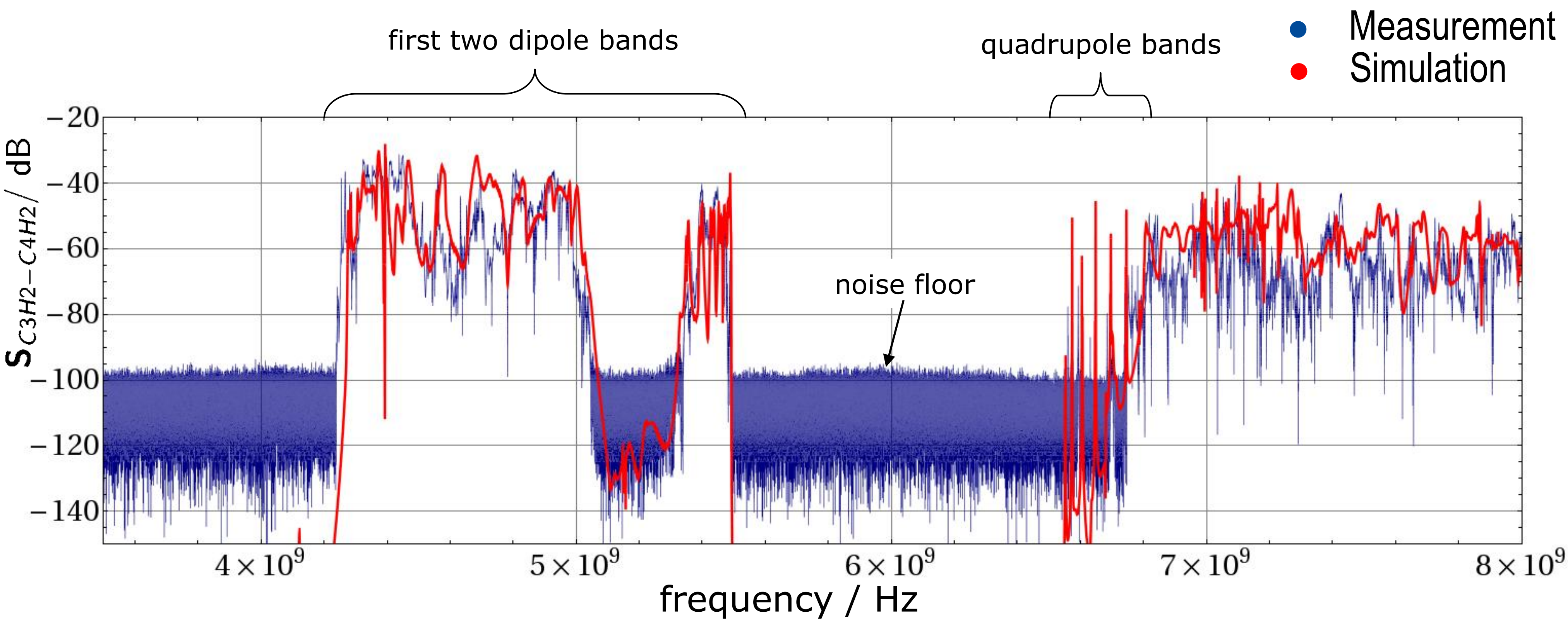
Example I: Transmission via Cavity 3



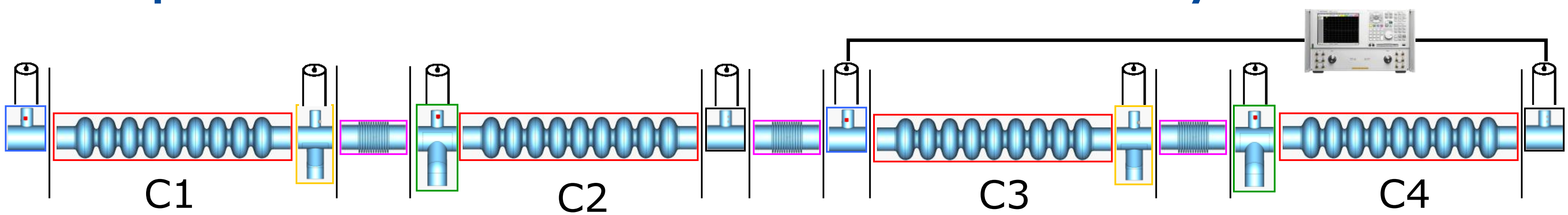


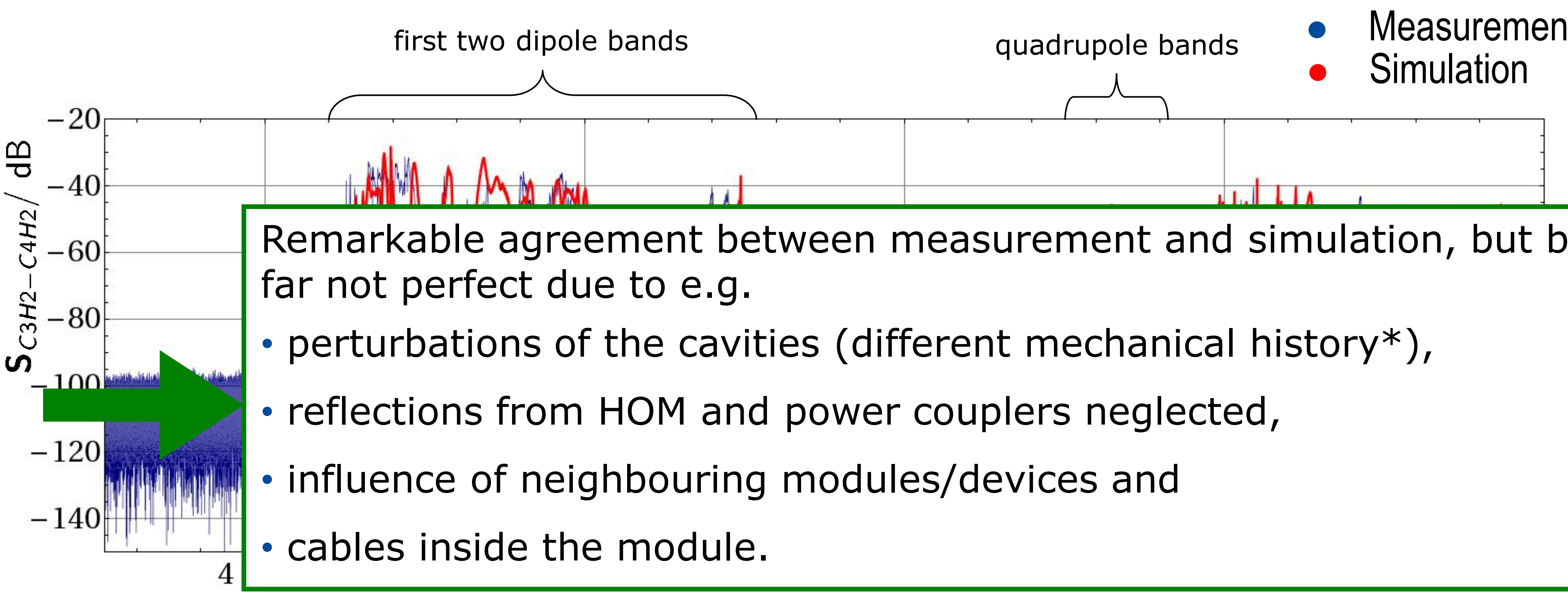
Example II: Transmission via Cavity 3 and 4





Example III: Transmission via Cavity 3 and 4



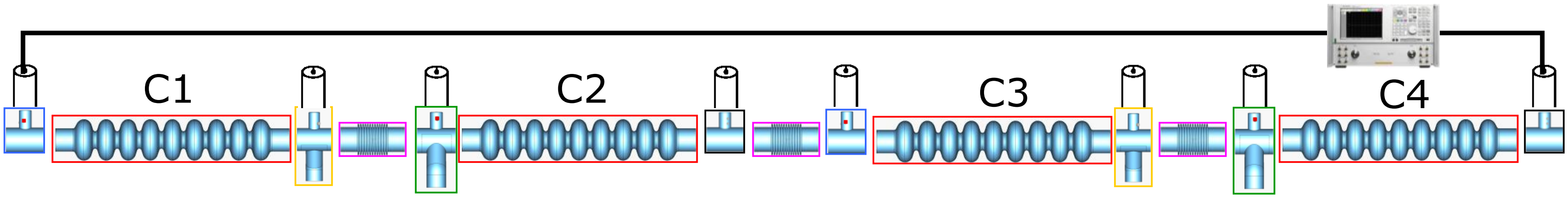


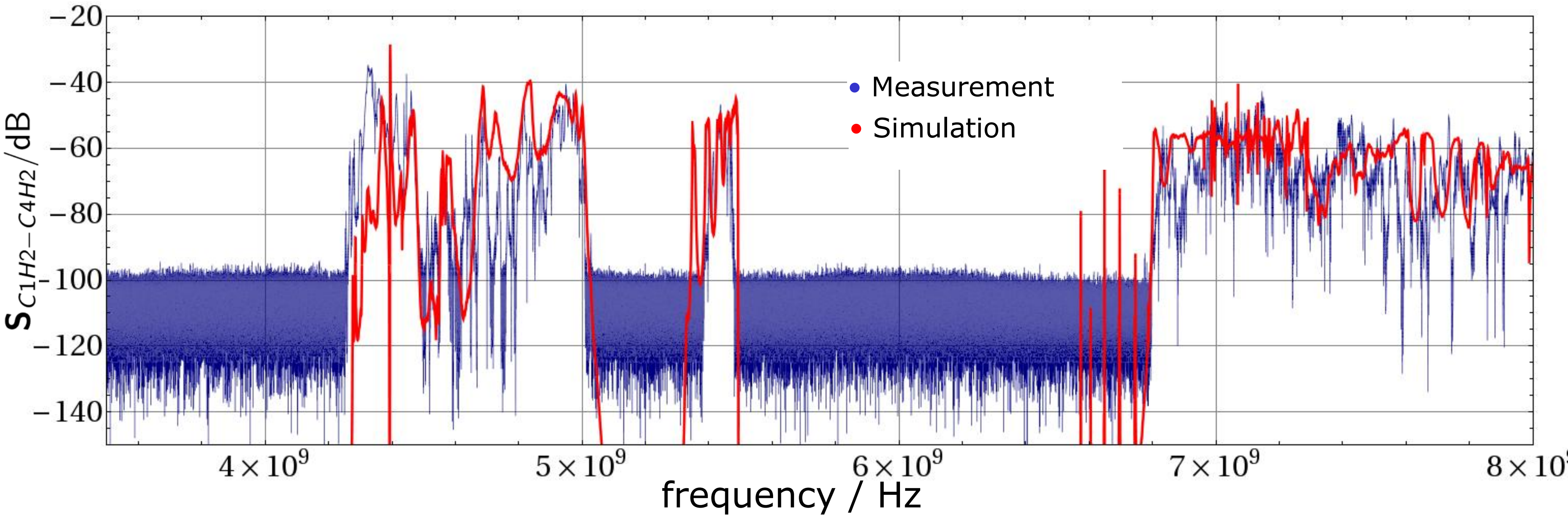
Remarkable agreement between measurement and simulation, but by far not perfect due to e.g.

- perturbations of the cavities (different mechanical history*),
- reflections from HOM and power couplers neglected,
- influence of neighbouring modules/devices and
- cables inside the module.

* T. Khabiboulline, privat communication, Oct. 2010

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

- Expensive to discretize entire structure for wakefield computation, yet
- 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.

A coupling scheme for computation of beam excited HOM signals based on CSC*

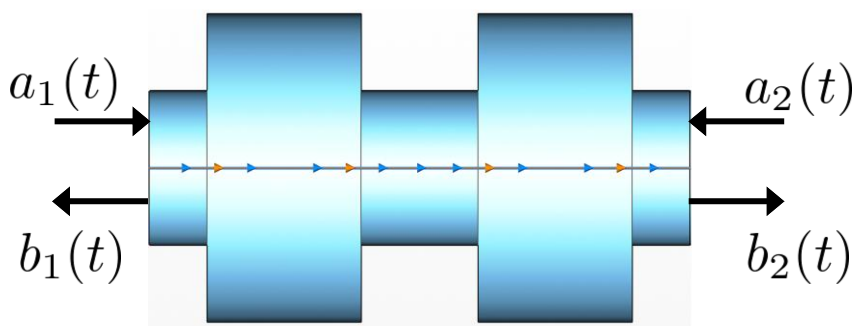
-

Coupled Time Domain Computations (CTC)

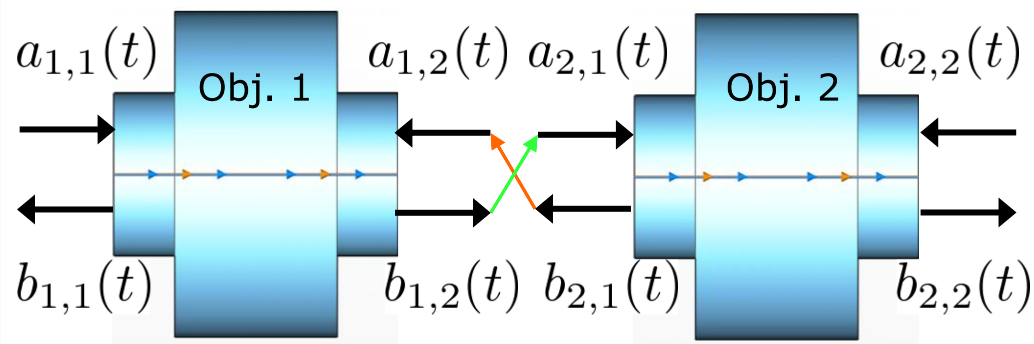
*T. Flisgen et al.: ”A Concatenation Scheme for the Computation of Beam Excited Higher Order Mode Port Signals”, Proceedings of IPAC2011, San Sebastián, Spain

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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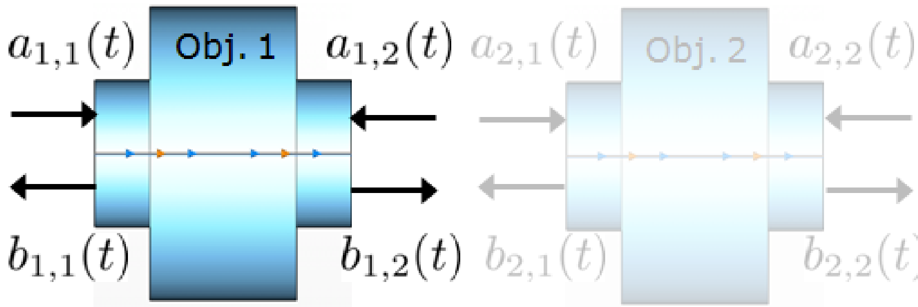
Scattered Signals in Ports of Substructure with Beam



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

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

incident transient signals at ports of object 1

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

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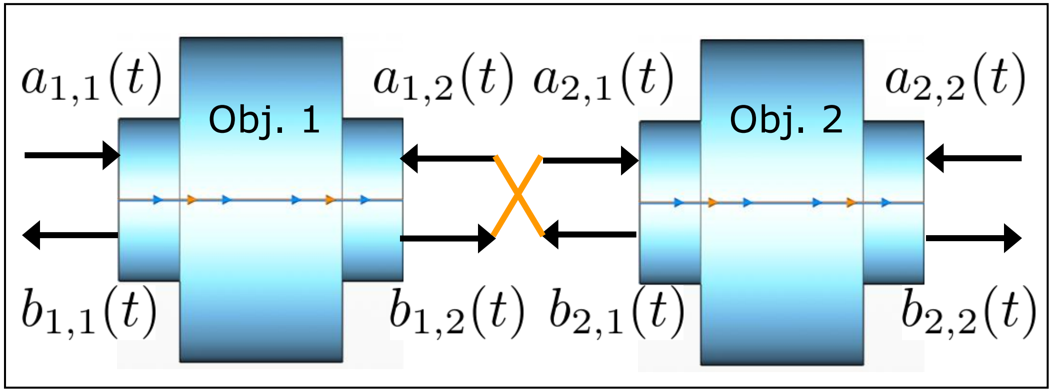
Coupling of two Elements

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

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

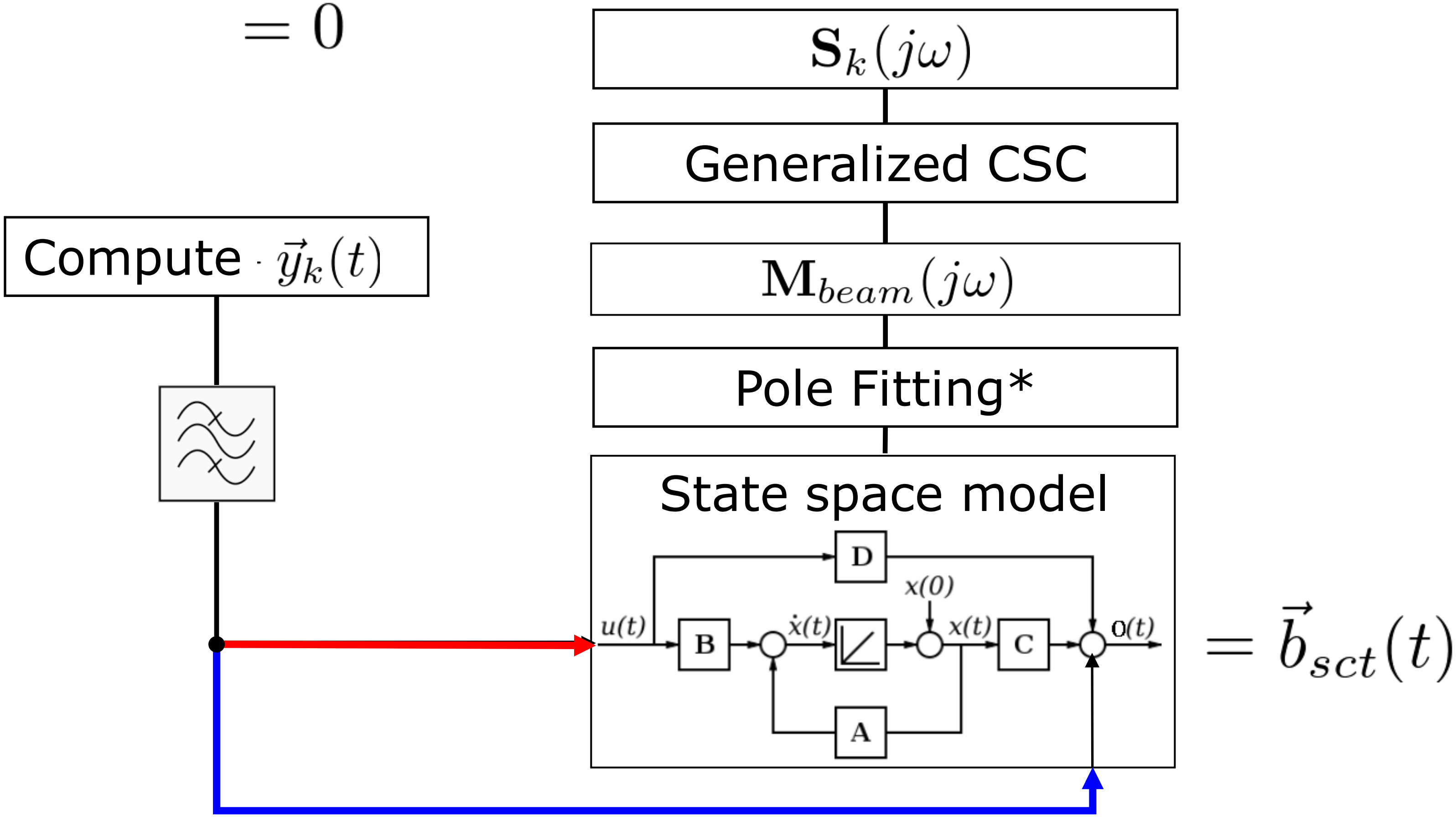


Plugging these equations together with topology information into CSC

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

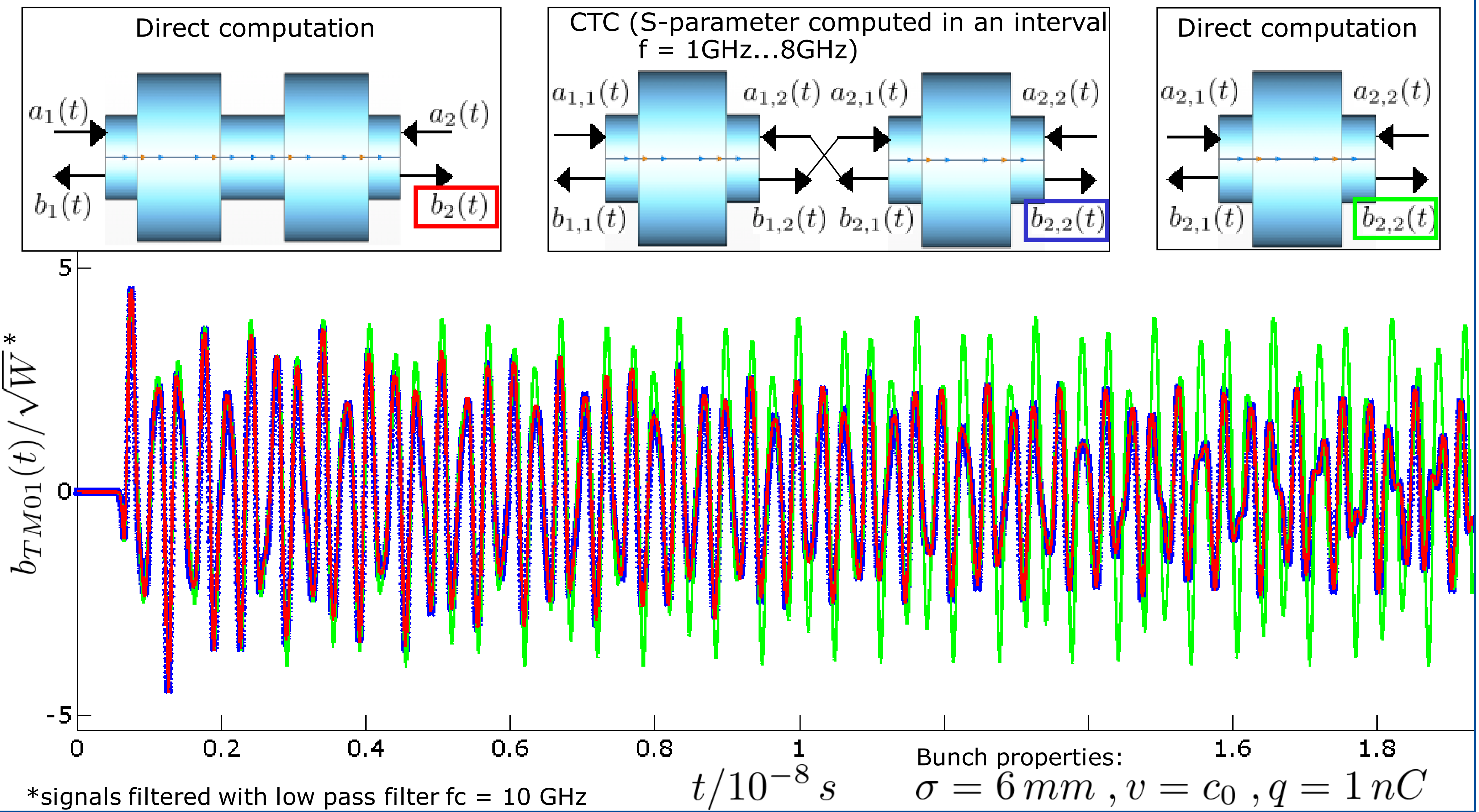
Computation of Transient Scattered Signals

$$\vec{b}_{sct}(t) = \underbrace{\mathbf{S}_{csc}(t) * \vec{a}_{inc}(t)}_{=0} + \mathbf{M}_{beam}(t) * \vec{y}_{int}(t) + \vec{y}_{ext}(t)$$



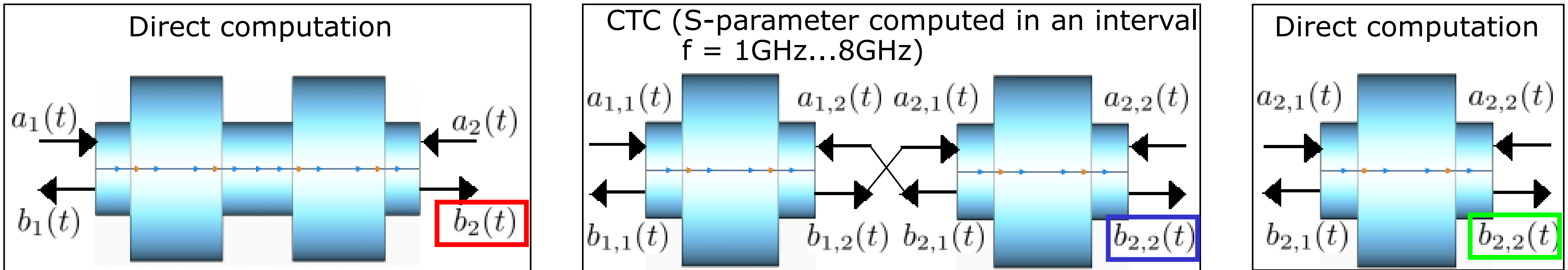
*H.-W. Glock et al.: "HOM Spectrum and Q-factor Estimations of the High-Beta CERN-SPL-Cavities", Proceedings of IPAC'10, Kyoto, Japan or
B. Gustavsen et al., "Rational approximation of frequency domain responses by vector fitting", IEEE Trans. Power Delivery, vol. 14, no. 3, pp. 1052-1061, July 1999.

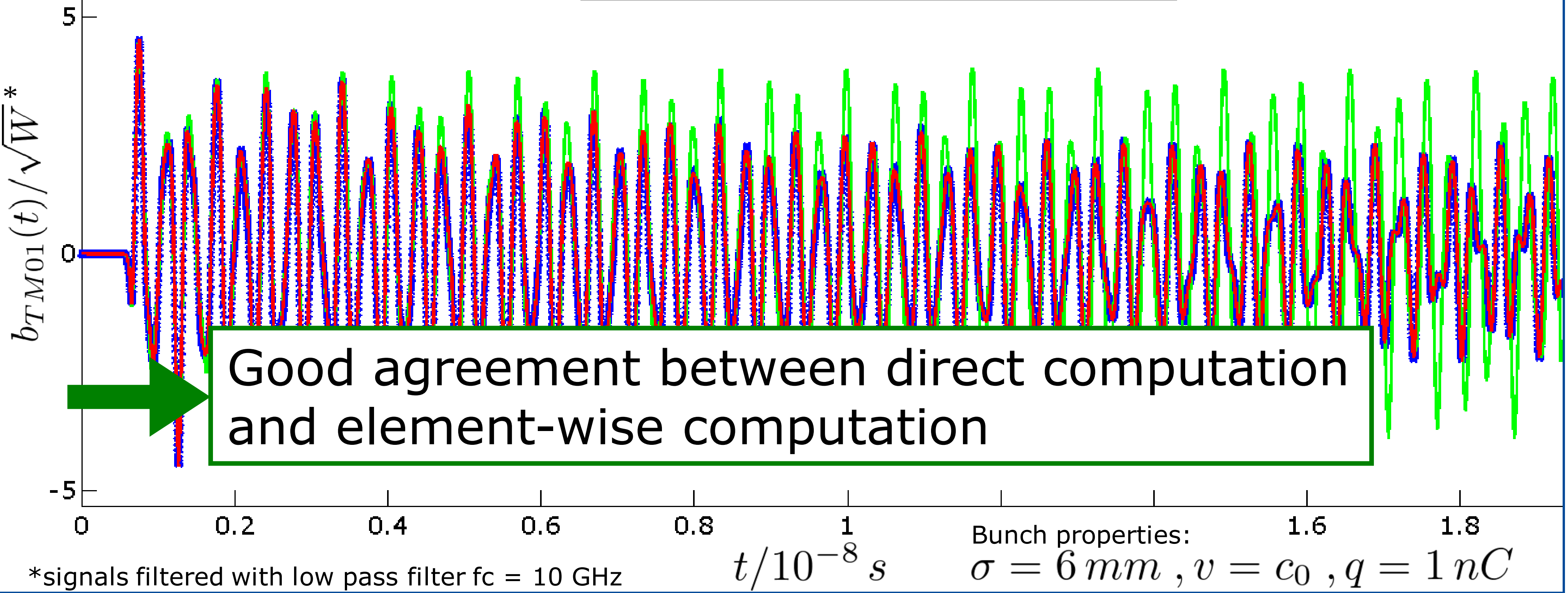
CTC - Proof of Principle



*signals filtered with low pass filter fc = 10 GHz

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

Measurement of Beam Excited HOM Signals using Diode Downmixing Scheme*

*H.-W. Glock et al.: ”Diode Down-mixing of HOM Coupler Signals for Beam Position Determination in 1.3-GHz- and 3.9-GHz-Cavities at FLASH”, Proceedings of DIPAC2011, Hamburg, Germany

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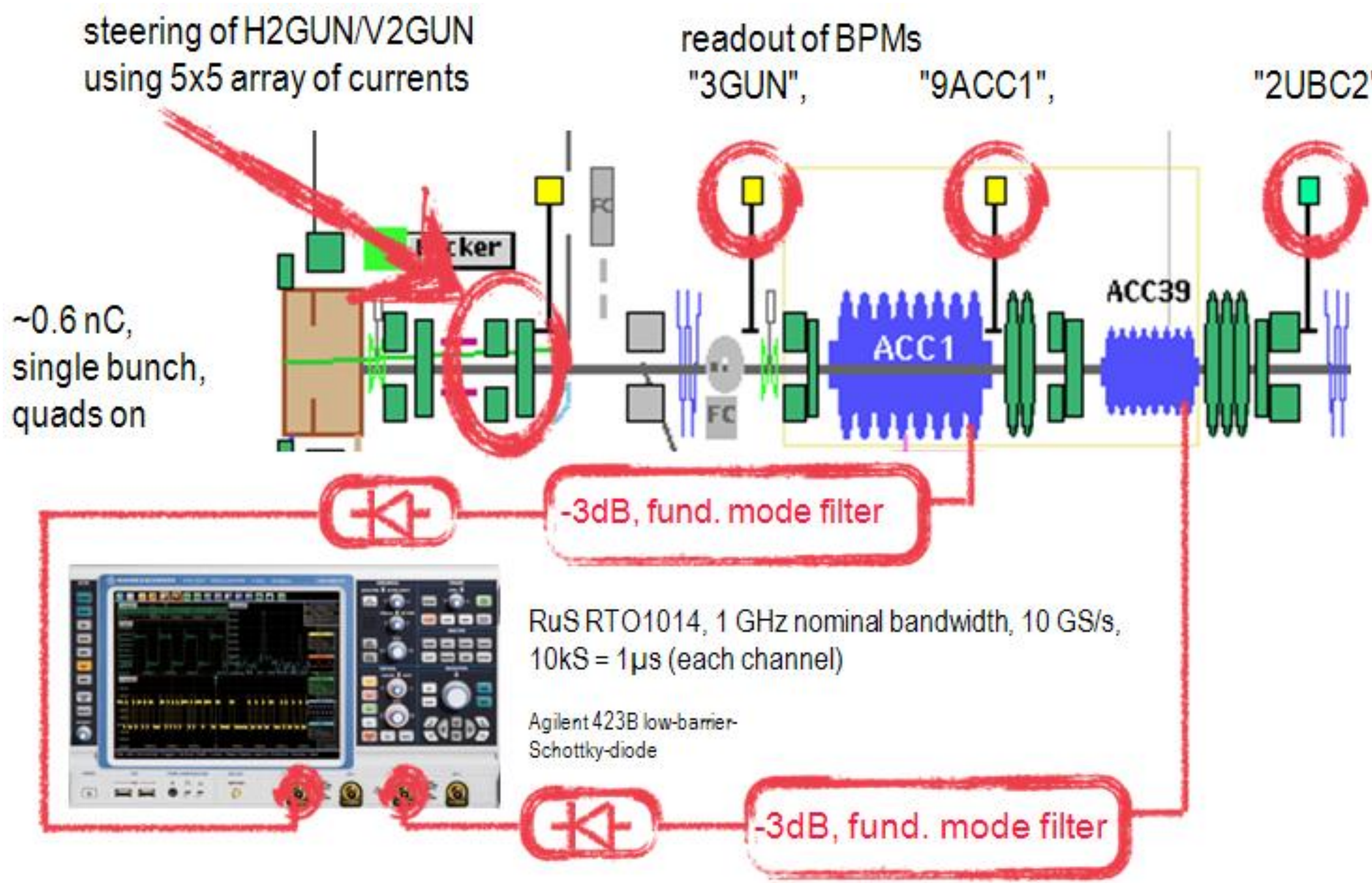
Taking in parallel signals from ACC1-C8H1 und ACC39-C4H2



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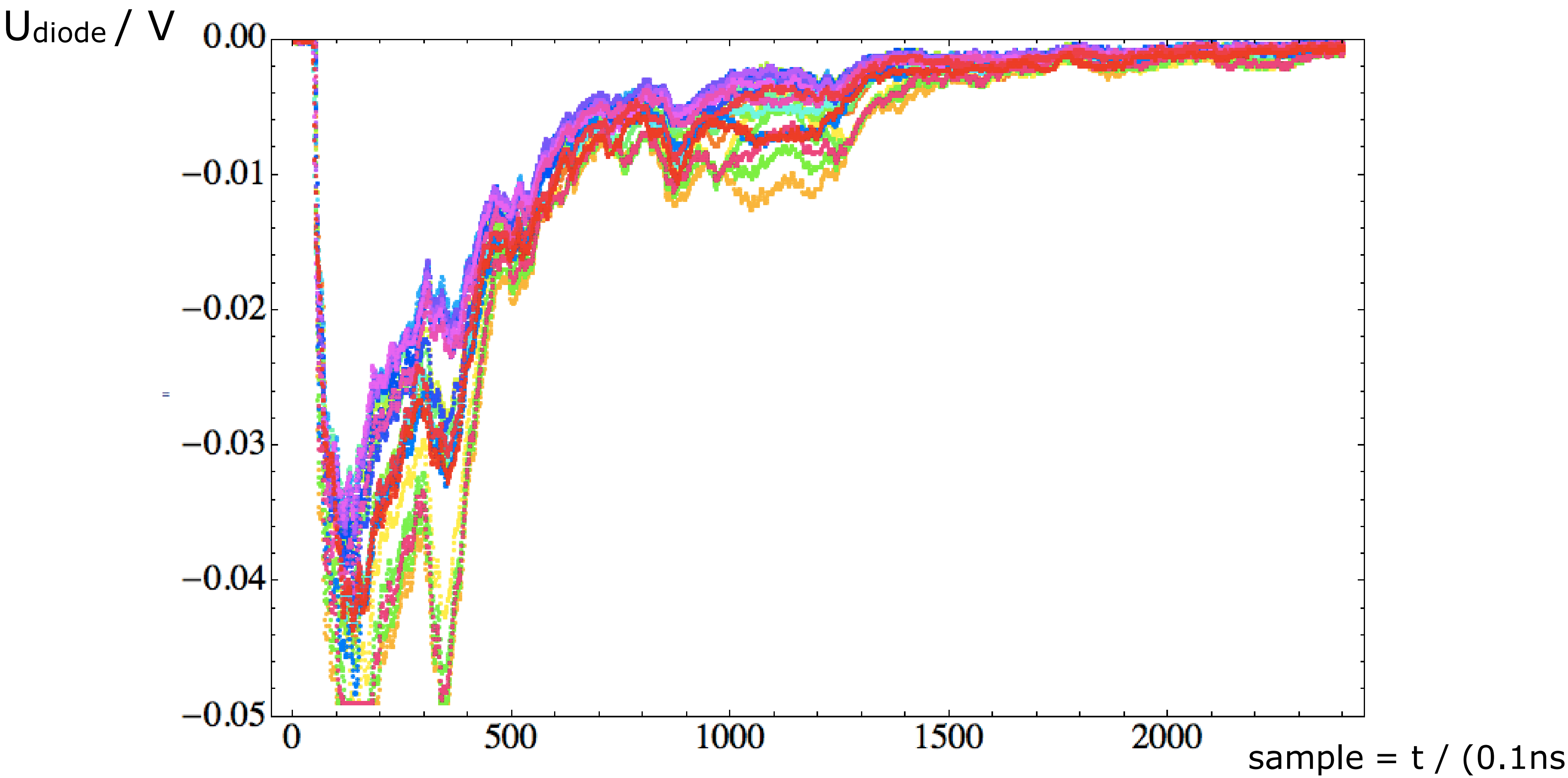
ACC39: All 24* (+1) raw diode voltage signals vs. time**

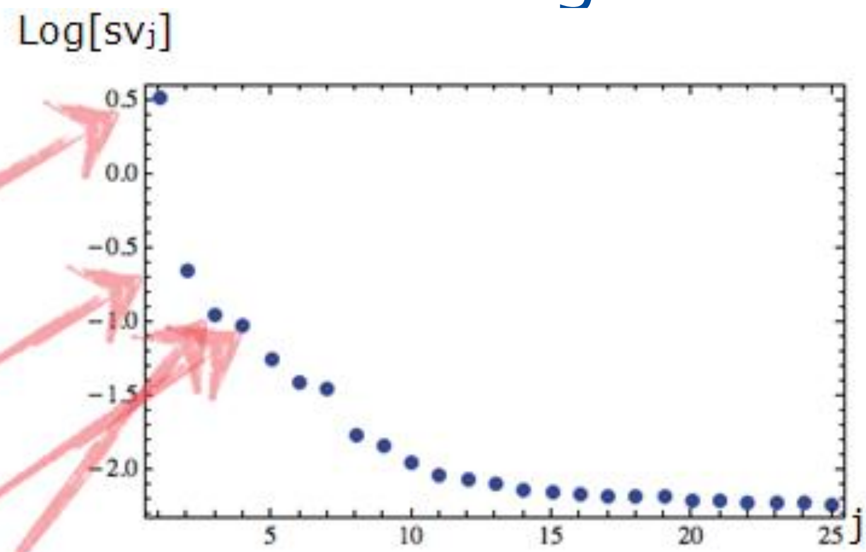


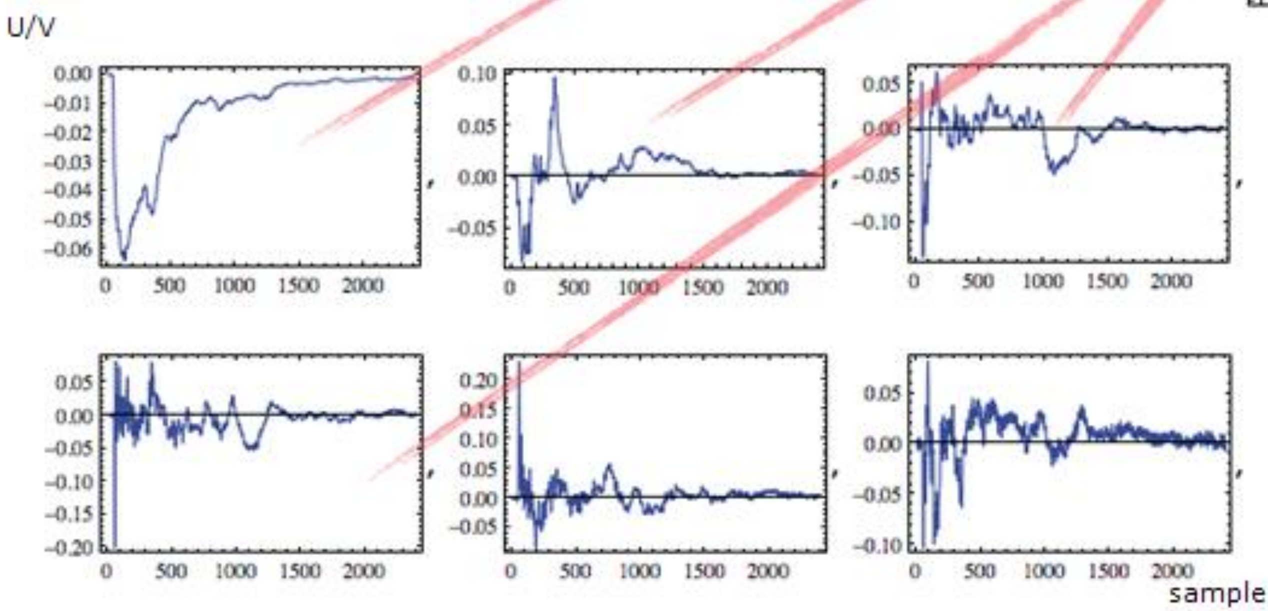
*: one position accidentally not stored
**: signal clipped in time covering only "interesting" range = 2400 samples = 0.24 μs

SVD basis vectors and weights for ACC39 signals

More than one order of magnitude between sv_1 and sv_2.

Approx. 4 dominant vectors.



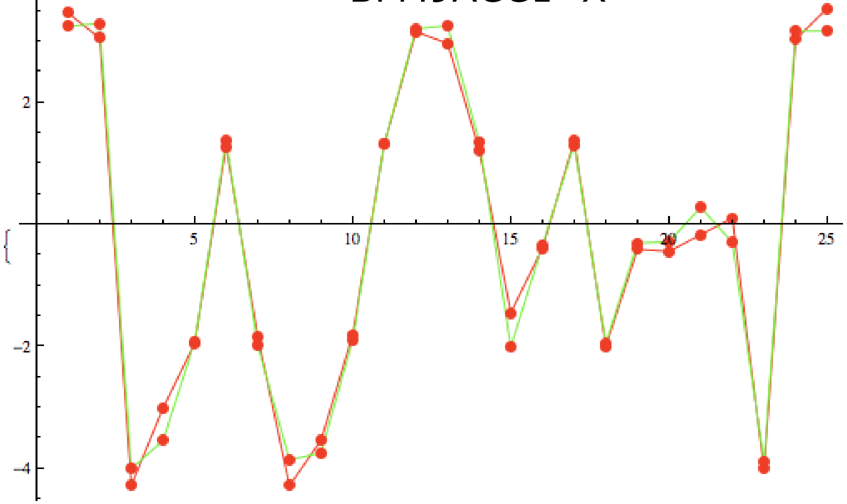


ACC39: svd-vecs 2-5 and using an bpm/signal offset

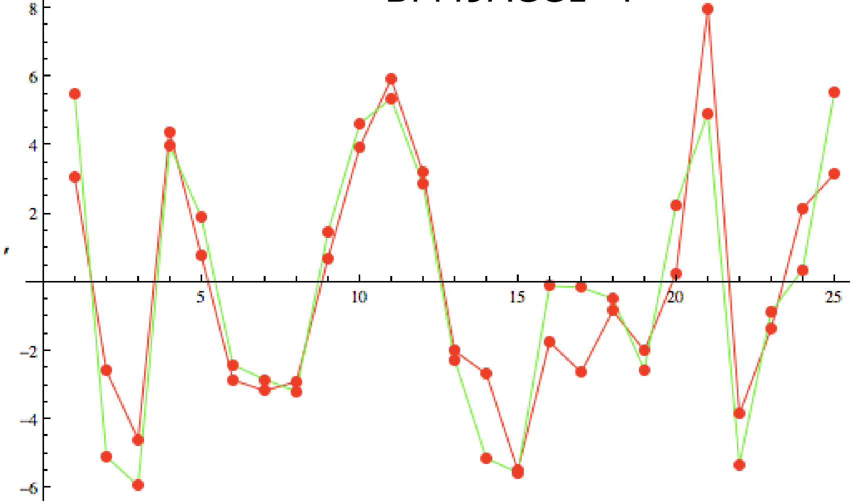
Measurement (green connection) vs. prediction (red)

all graphs mm vs. steerer configuration number

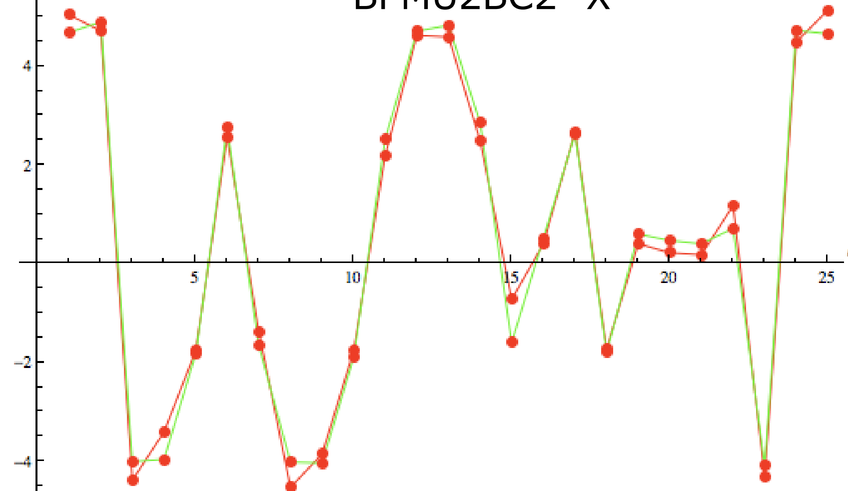
BPM9ACC1 -X



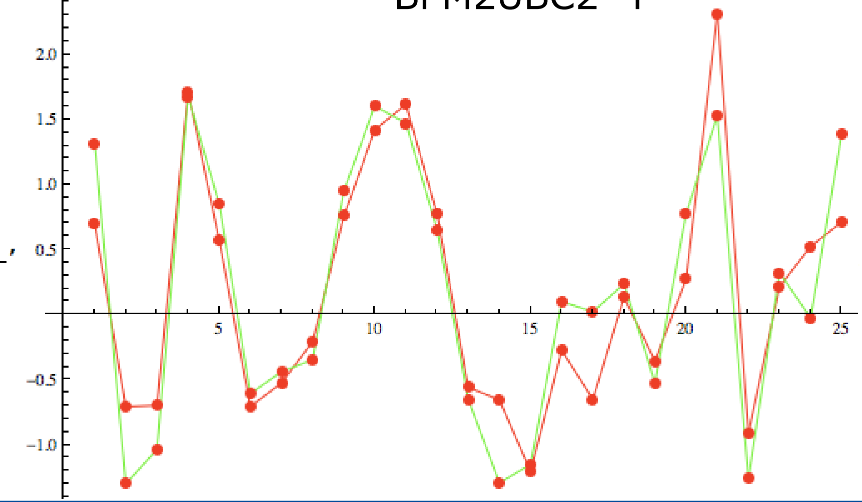
BPM9ACC1 -Y



BPMU2BC2 -X



BPM2UBC2 -Y



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

Measurement (green connection) vs. prediction (red)

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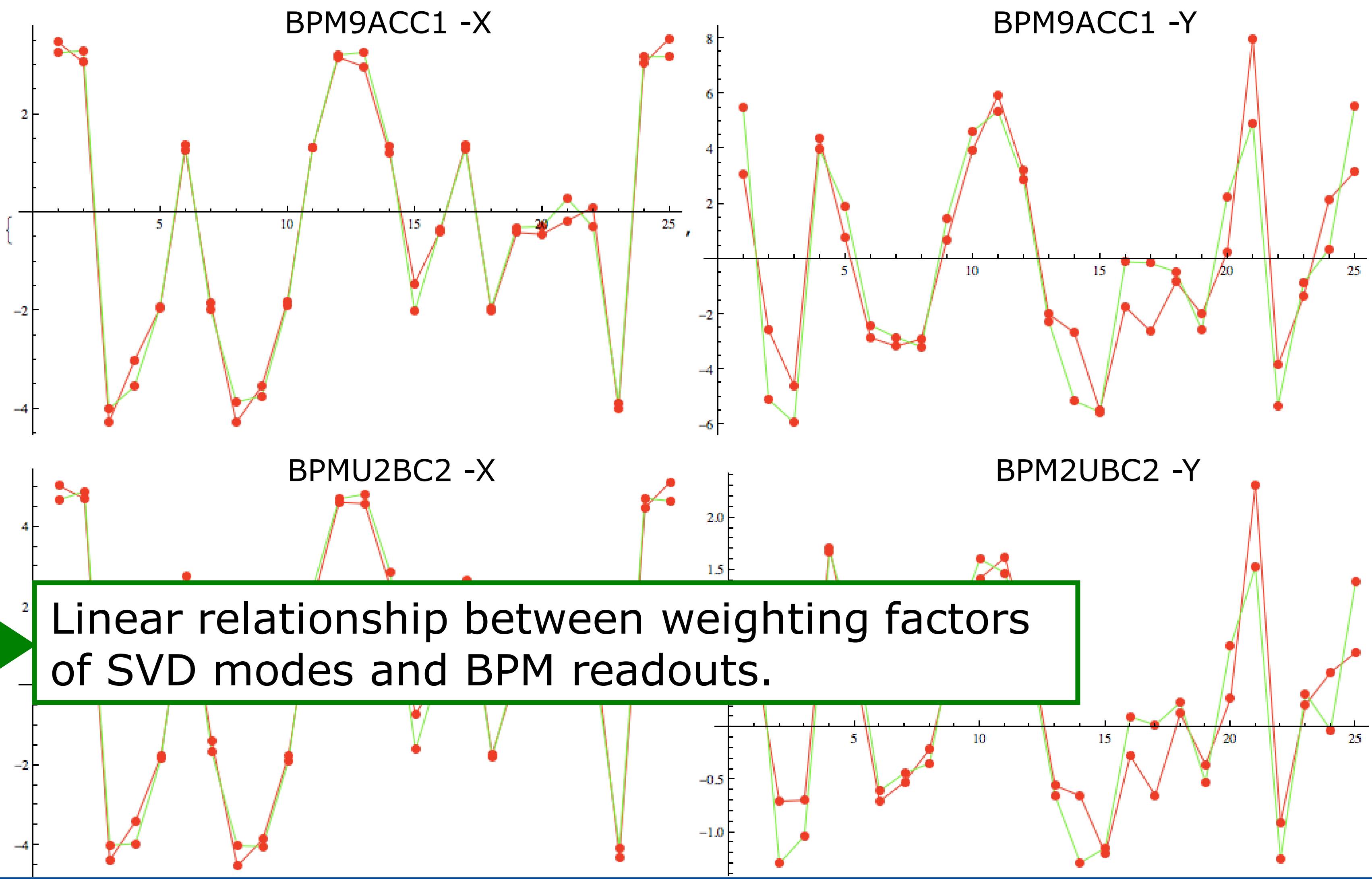

Linear relationship between weighting factors of SVD modes and BPM readouts.

Summary and Future Plans

Summary

- Comparison measurement and simulation of S-parameter of ACC39 shows a remarkable agreement.
- Scattering properties of ACC39 motivate the development of coupling scheme.
- Beam induced signals of complex structures can be computed using concatenation schemes.
- SVD weighting factors of diode-based measurements for HOM port signals correlate in a linear manner with BPM readouts.

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.
- Further analysis of evaluation schemes for diode based measurements to estimate resolution capabilities.