Study of Beam Diagnostics with Trapped Modes in 3rd Harmonic SC Cavities at FLASH

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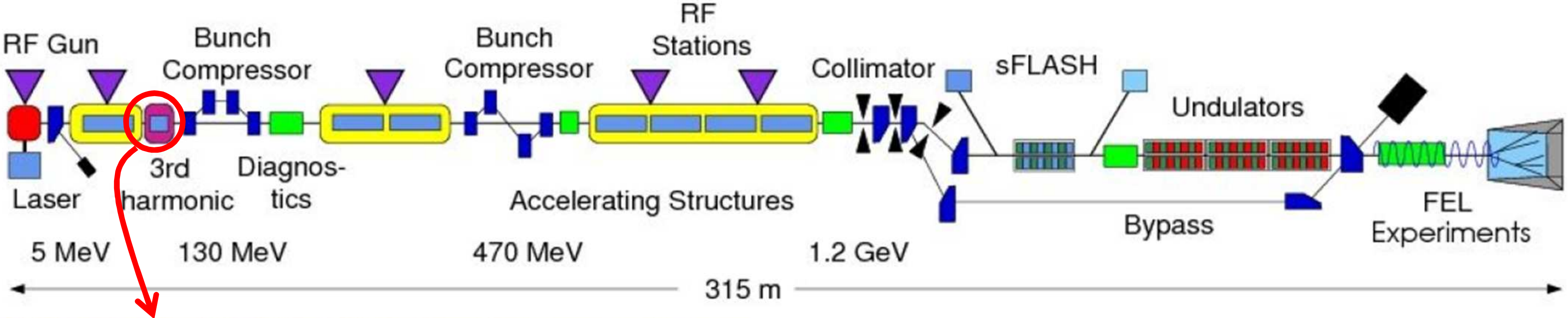
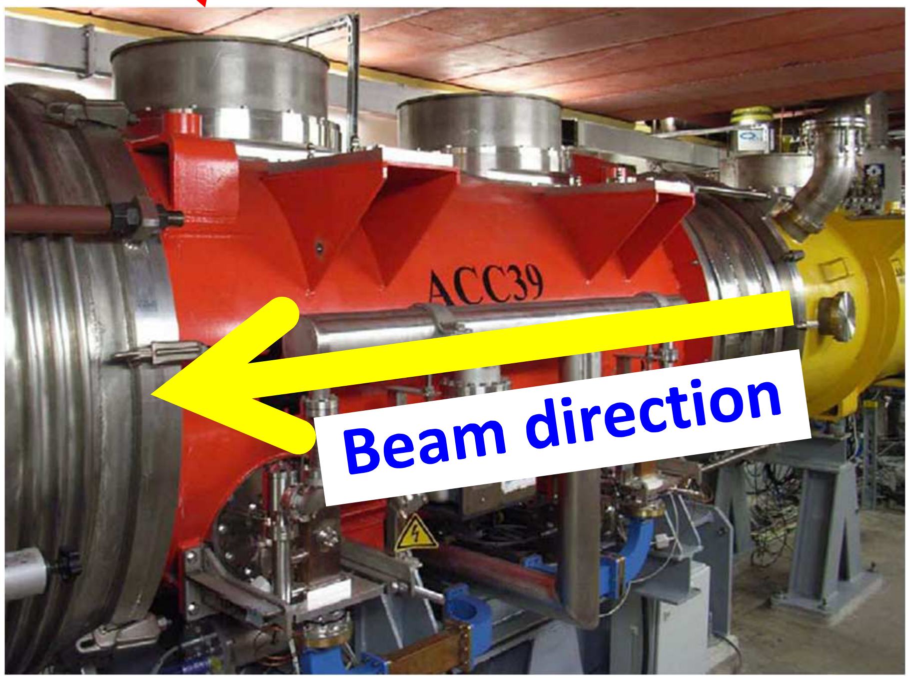
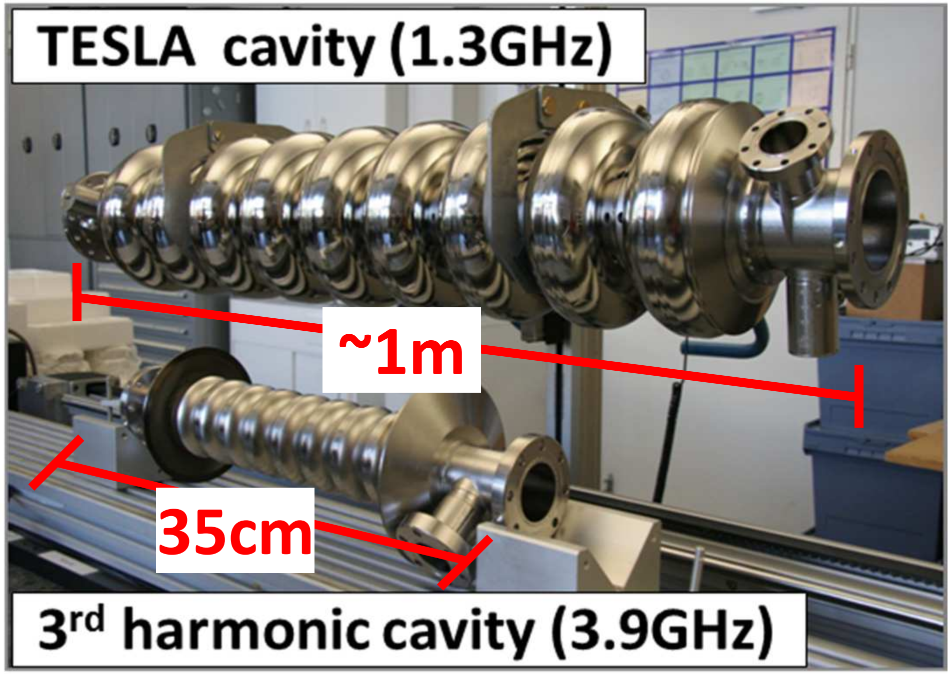
Sep 08th, 2011

FLASH and ACC39

Free-electron **LAS**er in **H**amburg (**FLASH**)







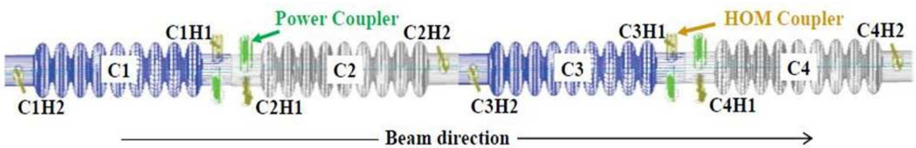


Photo courtesy E. Vogel & DESY

Motivation

- **Higher order modes (HOMs) are excited by charge particles in cavities**

- **Dipole modes dominate transverse wakefields**

$$W_{\perp} \approx \hat{x}\left(\frac{r'}{a}\right)\sum_{n}^{\infty}\frac{2k_{1n}}{\omega_{1n}\, a/c}\sin\frac{\omega_{1n} s}{c}$$

r': beam offset of excitation particle
a: iris radius

- **Use HOMs (non-monopole modes) to**

  - align the beam to the electric axis
  - monitor beam position (HOM-BPM)

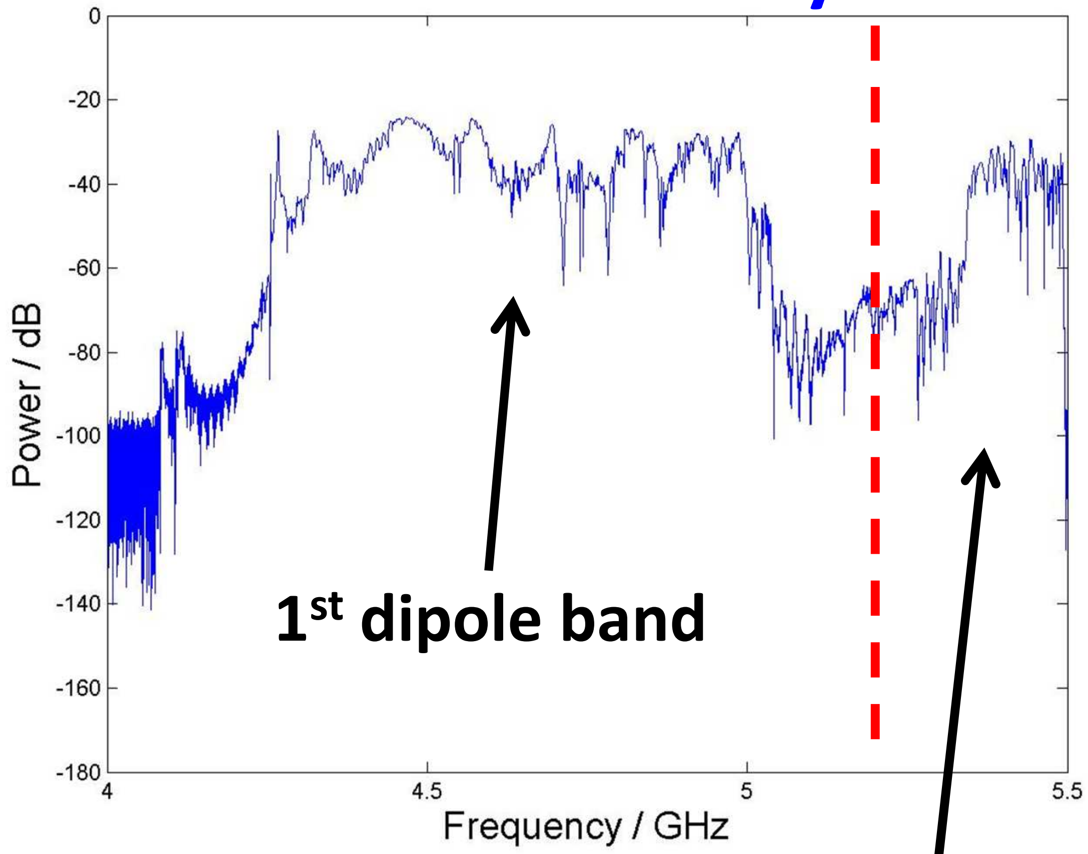
- **Principle proved in 1.3GHz Tesla cavity**

[1] G. Devanz et al., EPAC2002, WEAGB003
[2] N. Baboi et al., LINAC2004, MOP36
[3] S. Molloy et al., Phys. Rev. ST-AB 9, 112802 (2006)

Challenge

- **Most dipole modes propagate through attached beam pipes**

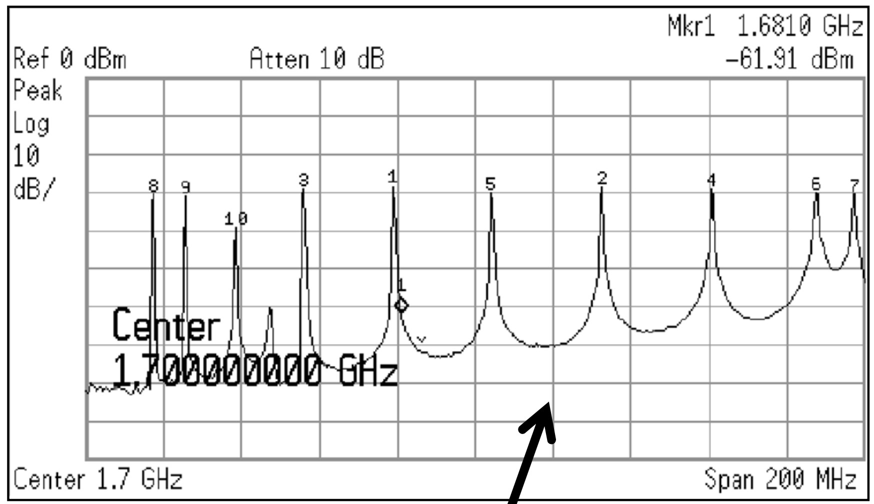
3.9 GHz Cavity



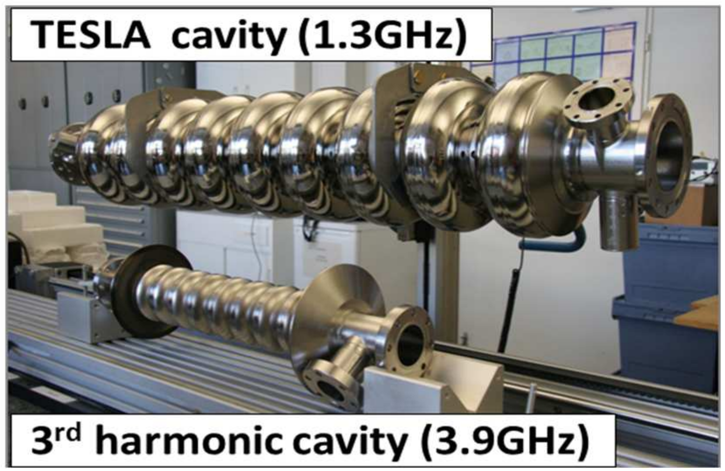
1st dipole band

2nd dipole band

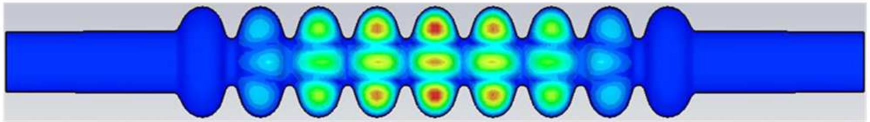
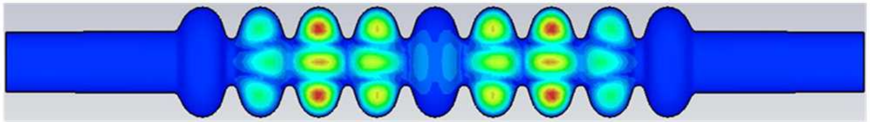
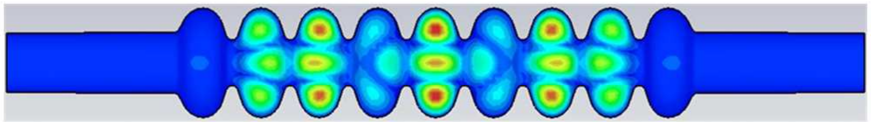
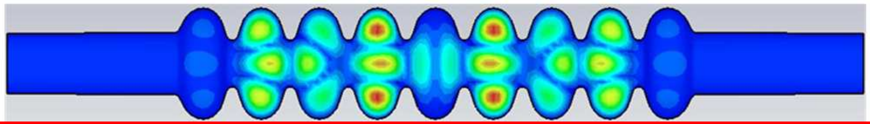
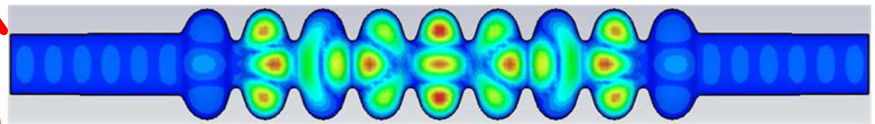
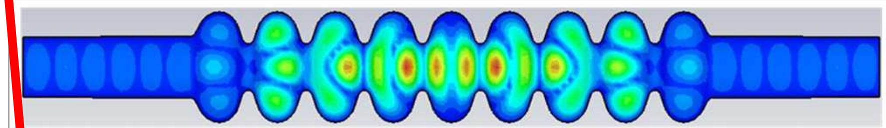
1.3 GHz Cavity

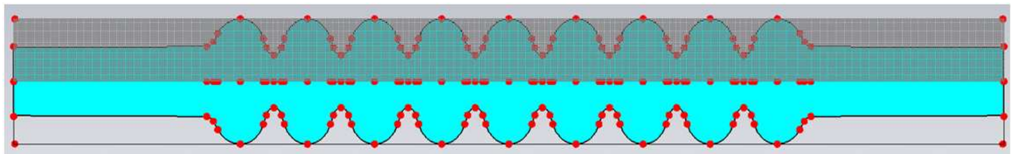


1st dipole band



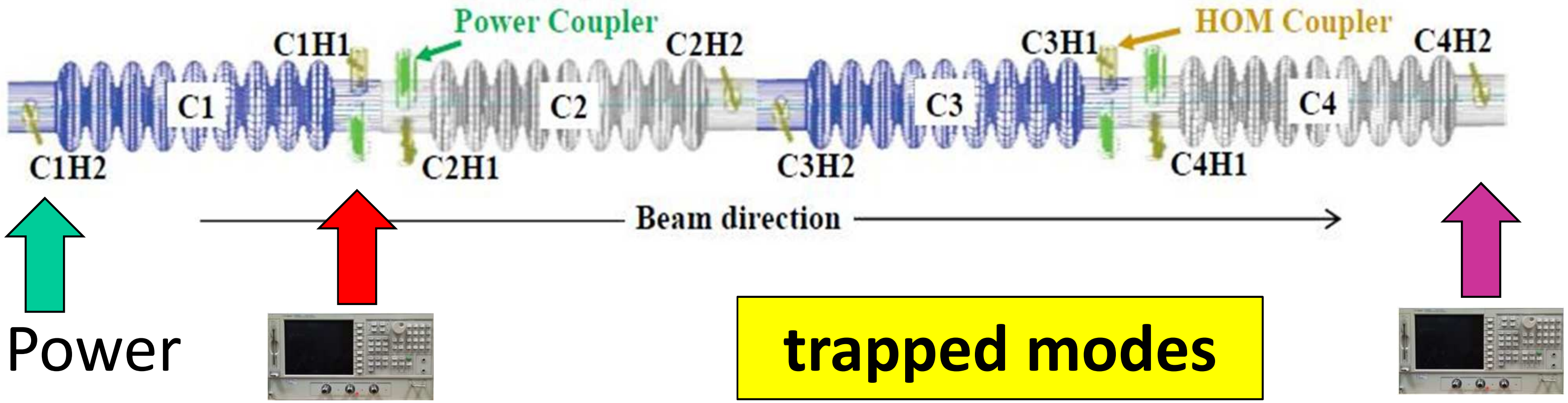
Simulation

Electric Field	f (GHz)	R/Q (Ω/cm²)
	9.052	0.00
	9.053	0.05
	9.055	0.06
	9.058	2.17
	9.066	4.12
	9.089	0.58



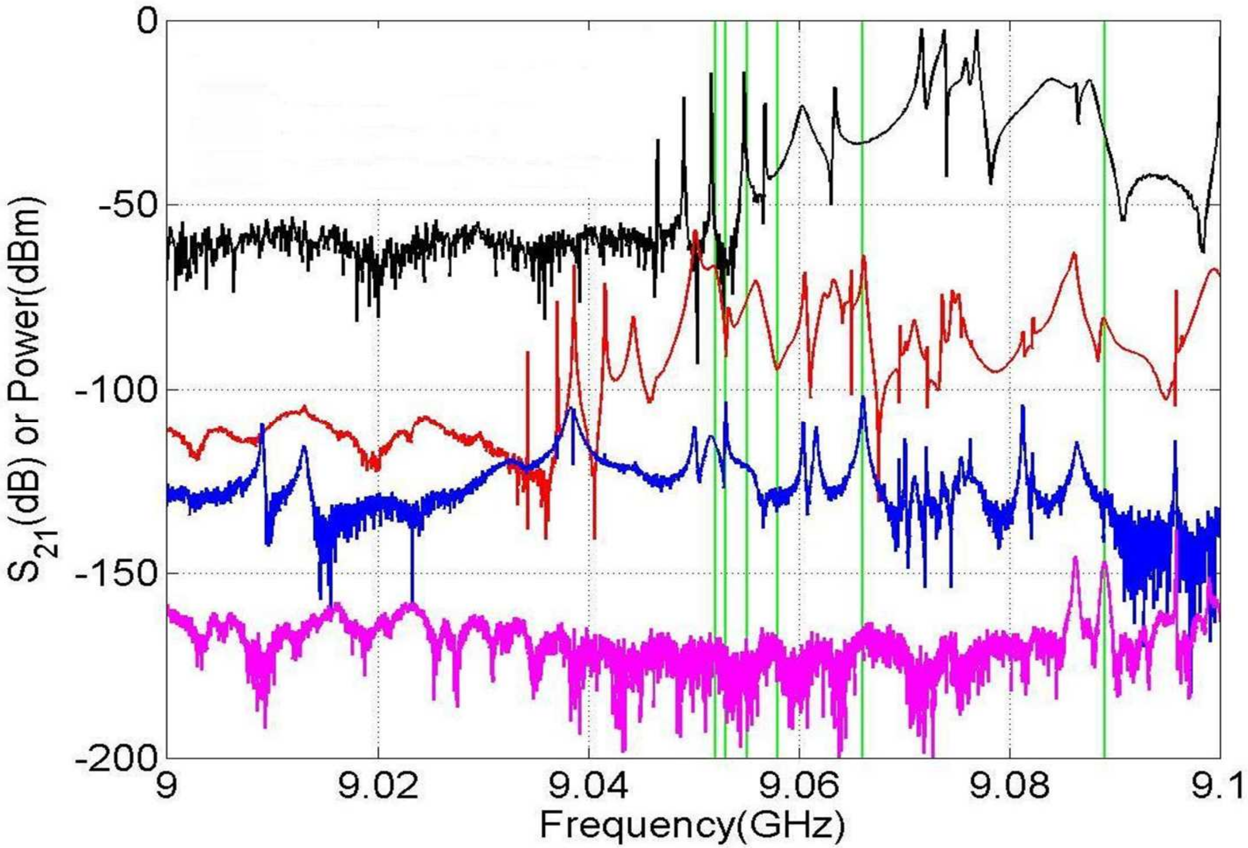
- Look like trapped
- Also seen in other simulations: I.R.R. Shinton, **WEPC125**

Measurements



Input Power

trapped modes



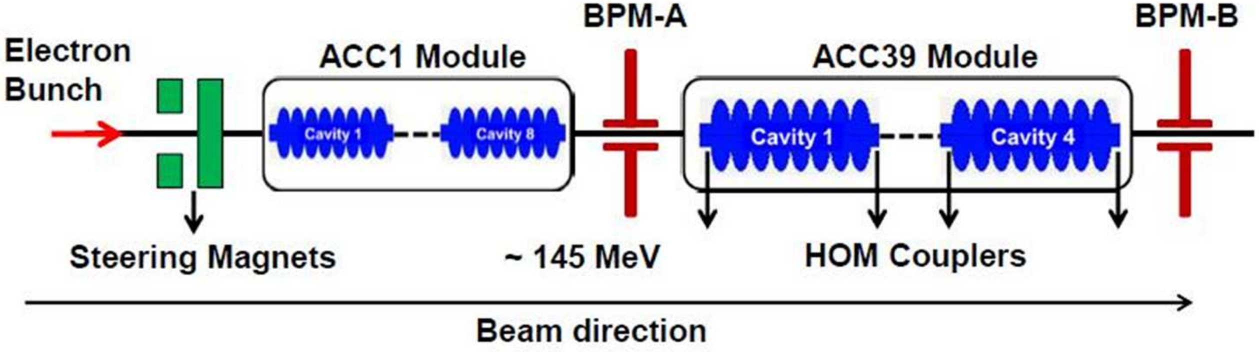
← Isolated cavity (across C1)

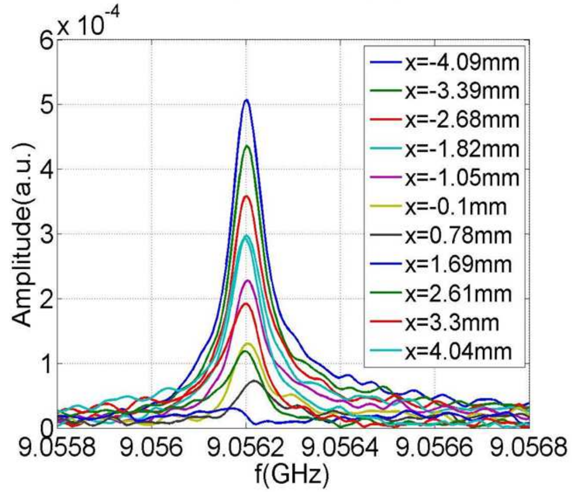
← S21 (across C1)

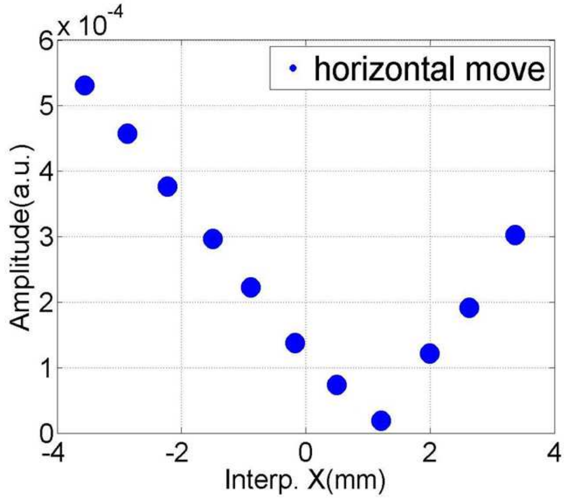
← Beam-excited (C1H1)

← S21 (across 4-cavity string)

Dipole-like Behavior

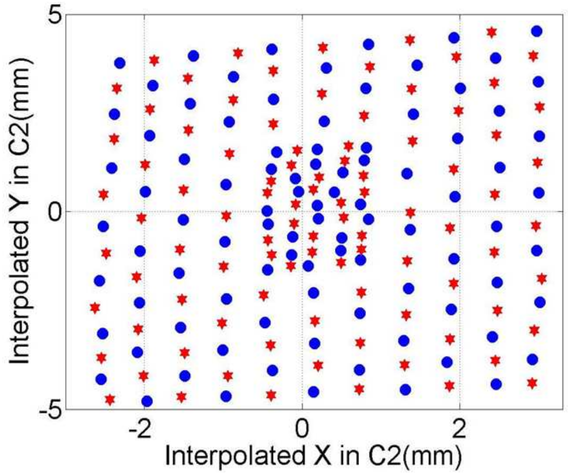


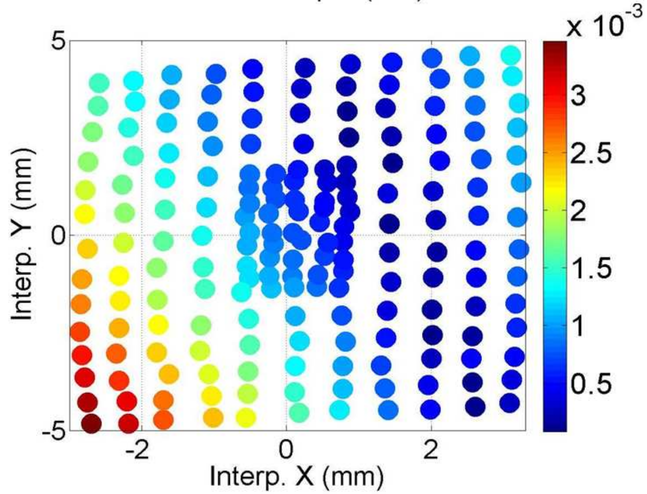




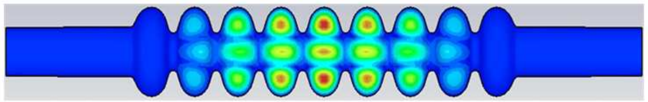
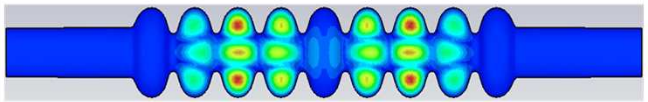
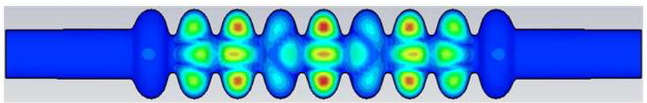
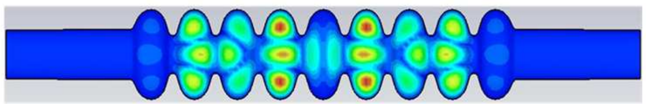
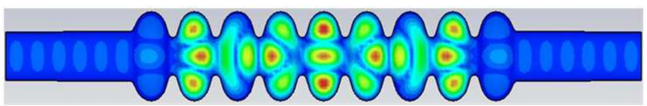
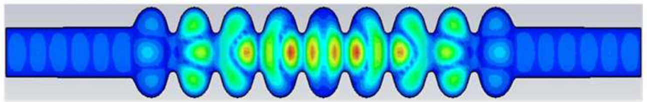
- Move the beam horizontally
- Grid-like move: polarization

trapped dipole modes



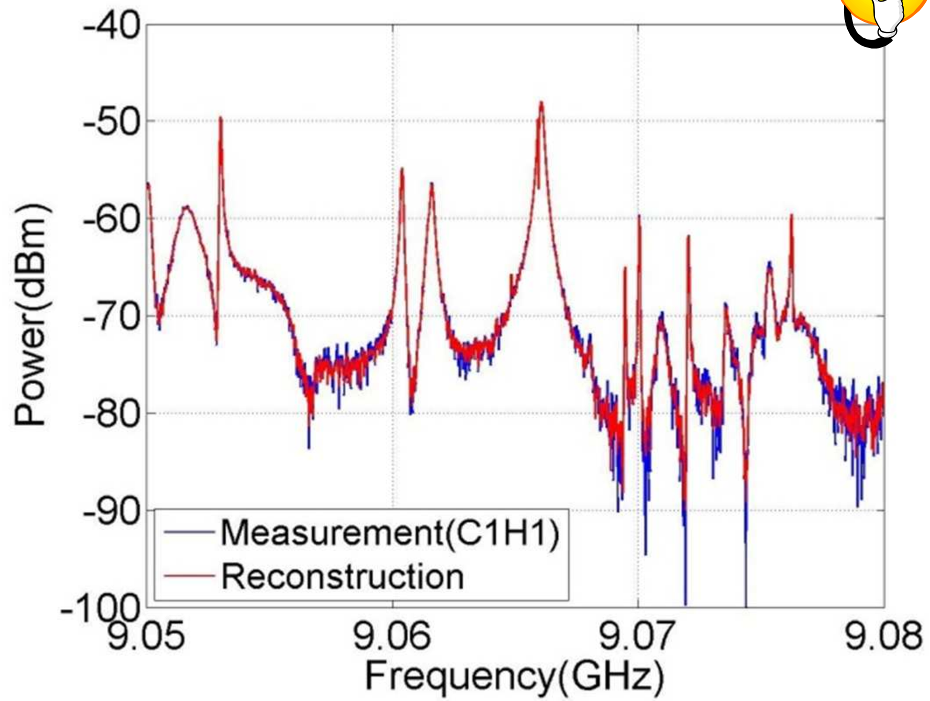


One mode is not enough

Electric Field	f (GHz)	R/Q (Ω/cm²)
	9.052	0.00
	9.053	0.05
	9.055	0.06
	9.058	2.17
	9.066	4.12
	9.089	0.58

too small

Use more modes



1.3 GHz TESLA cavity

Dipole passband	Mode #	f (GHz)	R/Q (Ω/cm²)
Band 1 (TE-like)	6	1.7129	5.5366
	7	1.7391	7.7833

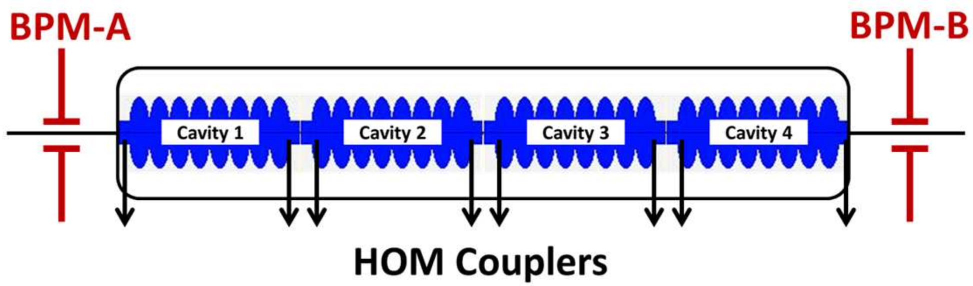
Direct Linear Regression (DLR)

$$A = \begin{pmatrix} spectrum_1 \\ \vdots \\ spectrum_N \end{pmatrix}$$

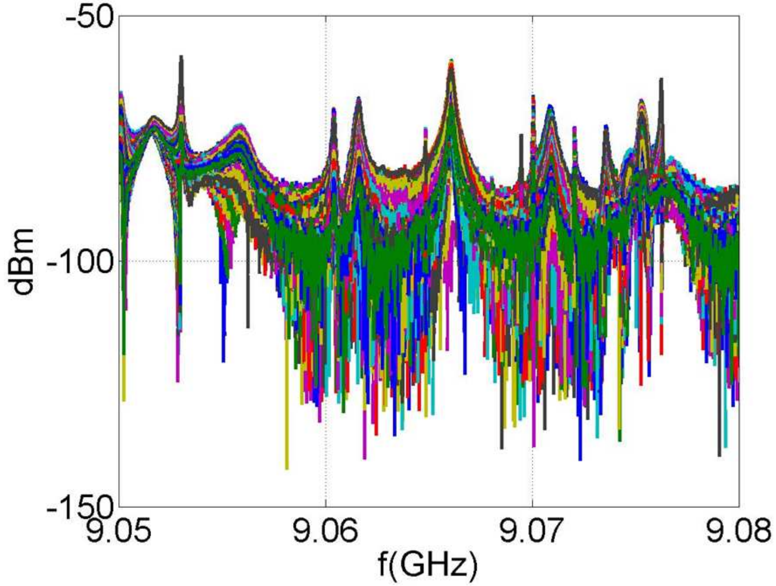
Coefficient matrix

$$B = \begin{pmatrix} x_1 & y_1 \\ \vdots & \vdots \\ x_N & y_N \end{pmatrix}$$

$$A \cdot M = B$$

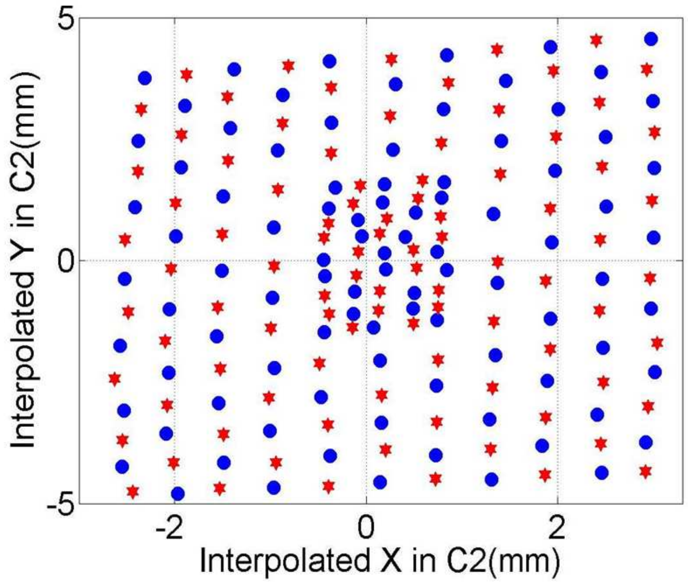


184 spectra

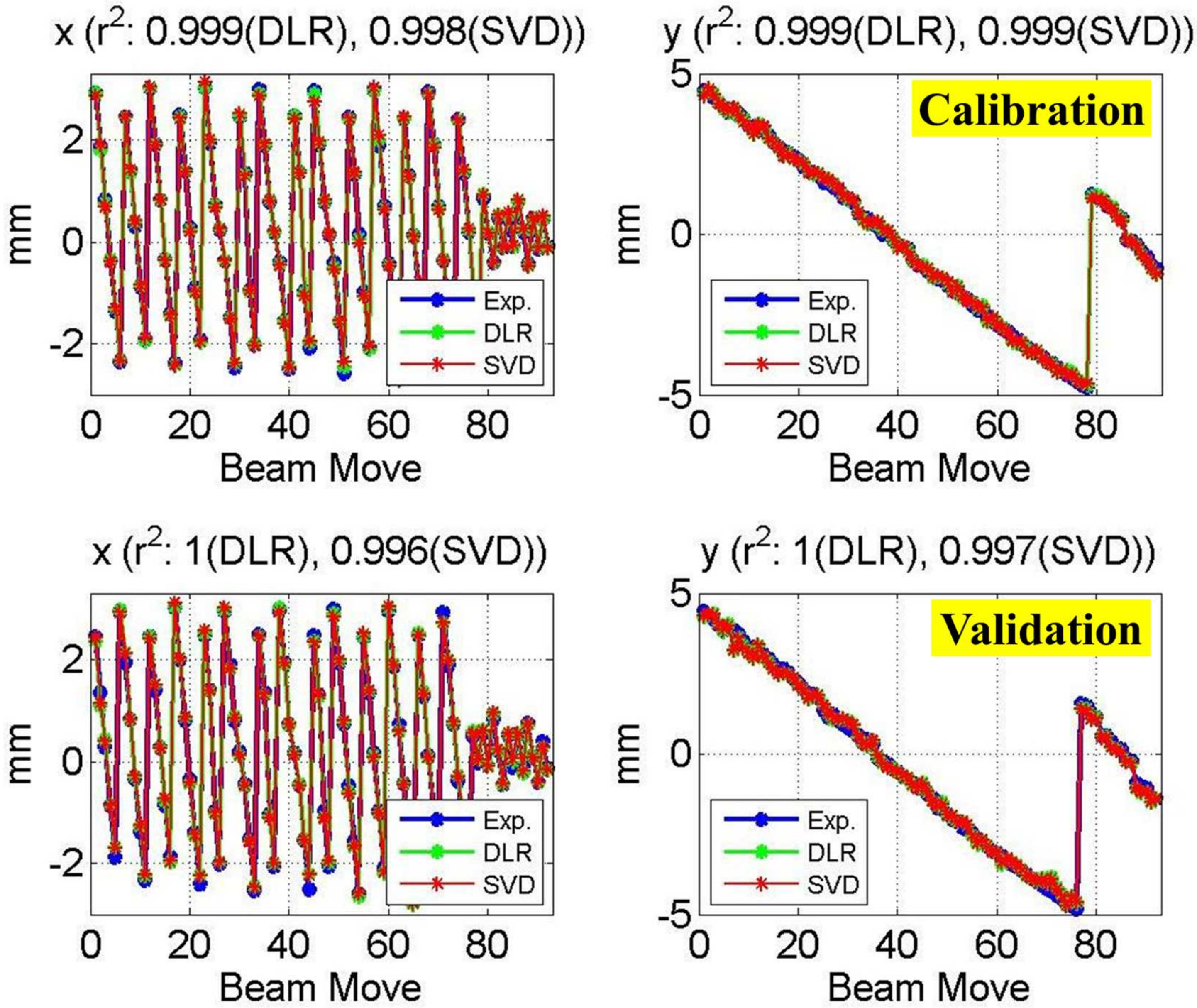


Two steps:

1. Calibration
2. Validation



Performance (DLR)



$$r^2 = 1 - \frac{\sum_{i=1}^{n}\left(B_i^{pre} - B_i\right)^2}{\sum_{i=1}^{n}\left(B_i - \overline{B}\right)^2}$$

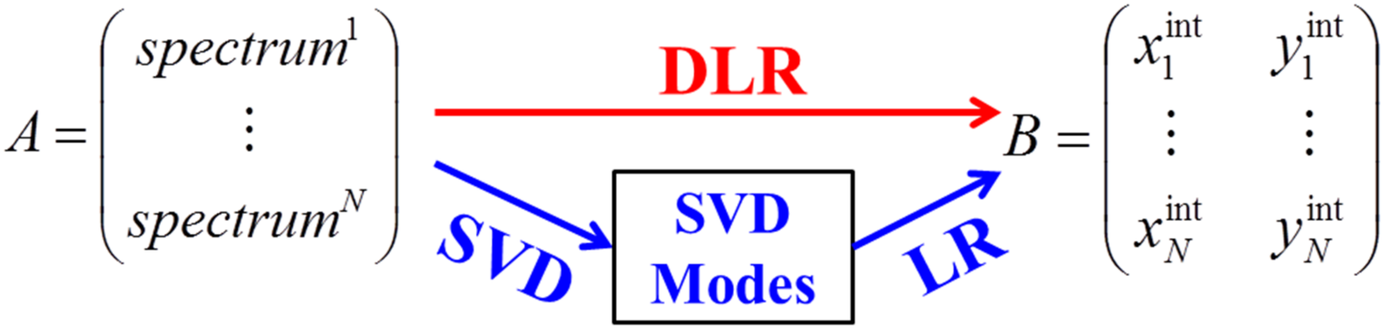
r^2 = 1, perfect fit

r^2 = 0, bad fit

Singular Value Decomposition (SVD)

DLR

$$A \cdot M = B$$ → Too many coefficients



SVD

$$A = U \cdot S \cdot V^T \longrightarrow A_S$$

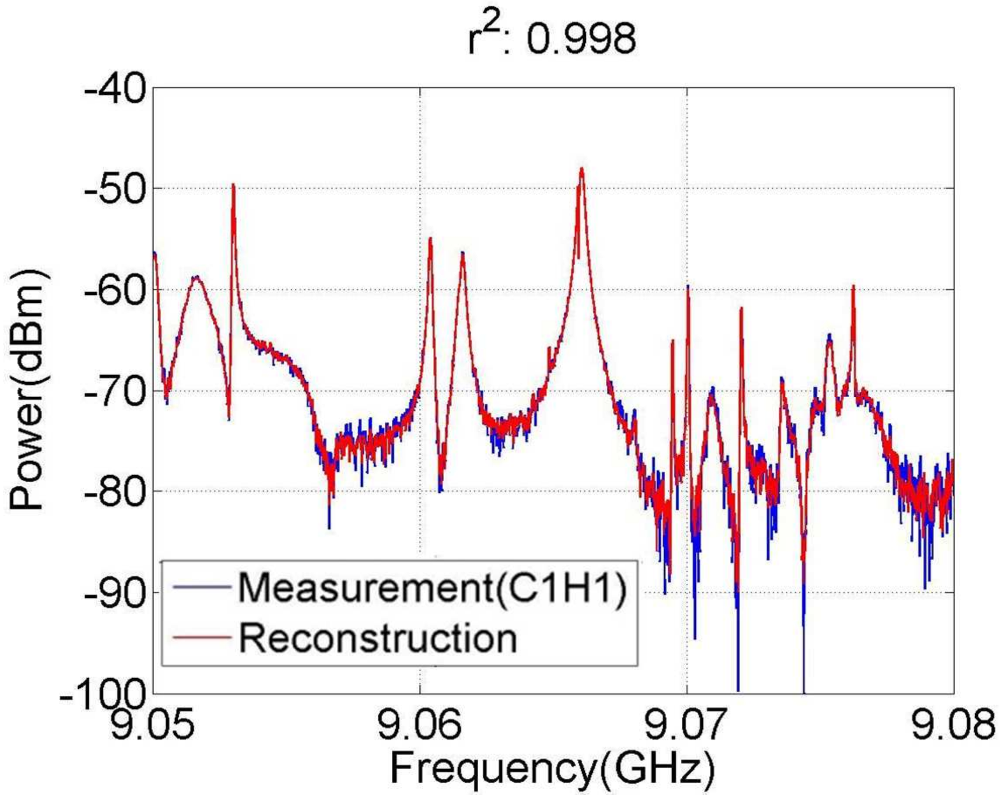
Size(**A**) = 1000's

Size(**A$_S$**) = 10's

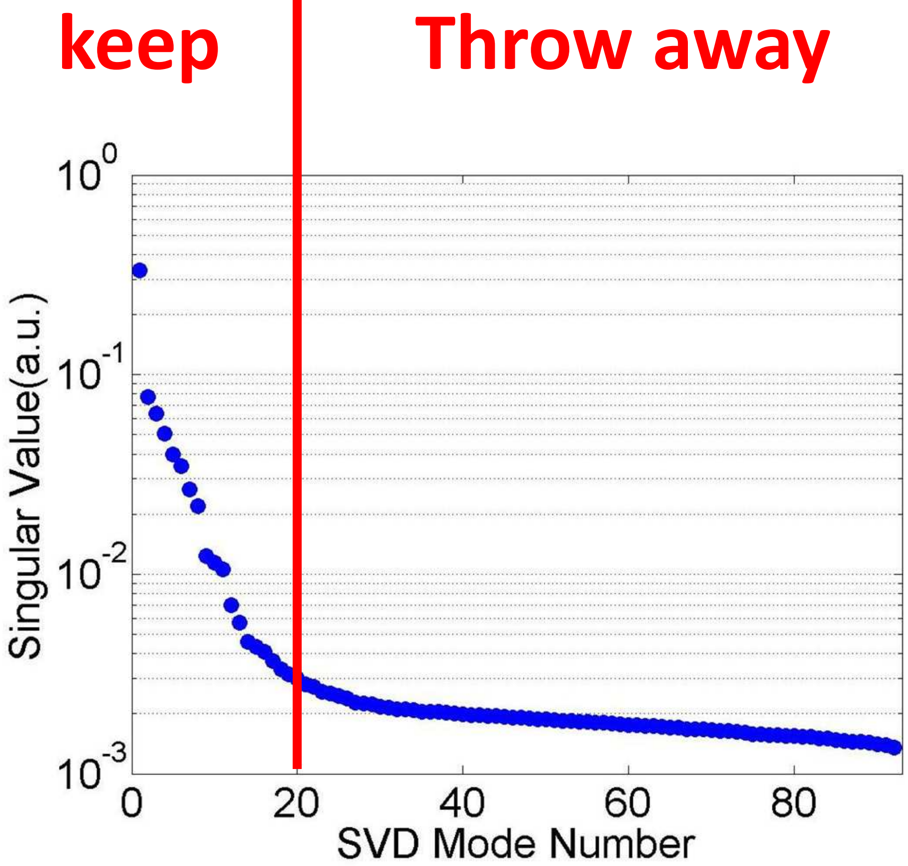
$$A_S \cdot M_S = B$$

→ Much fewer coefficients

SVD Modes

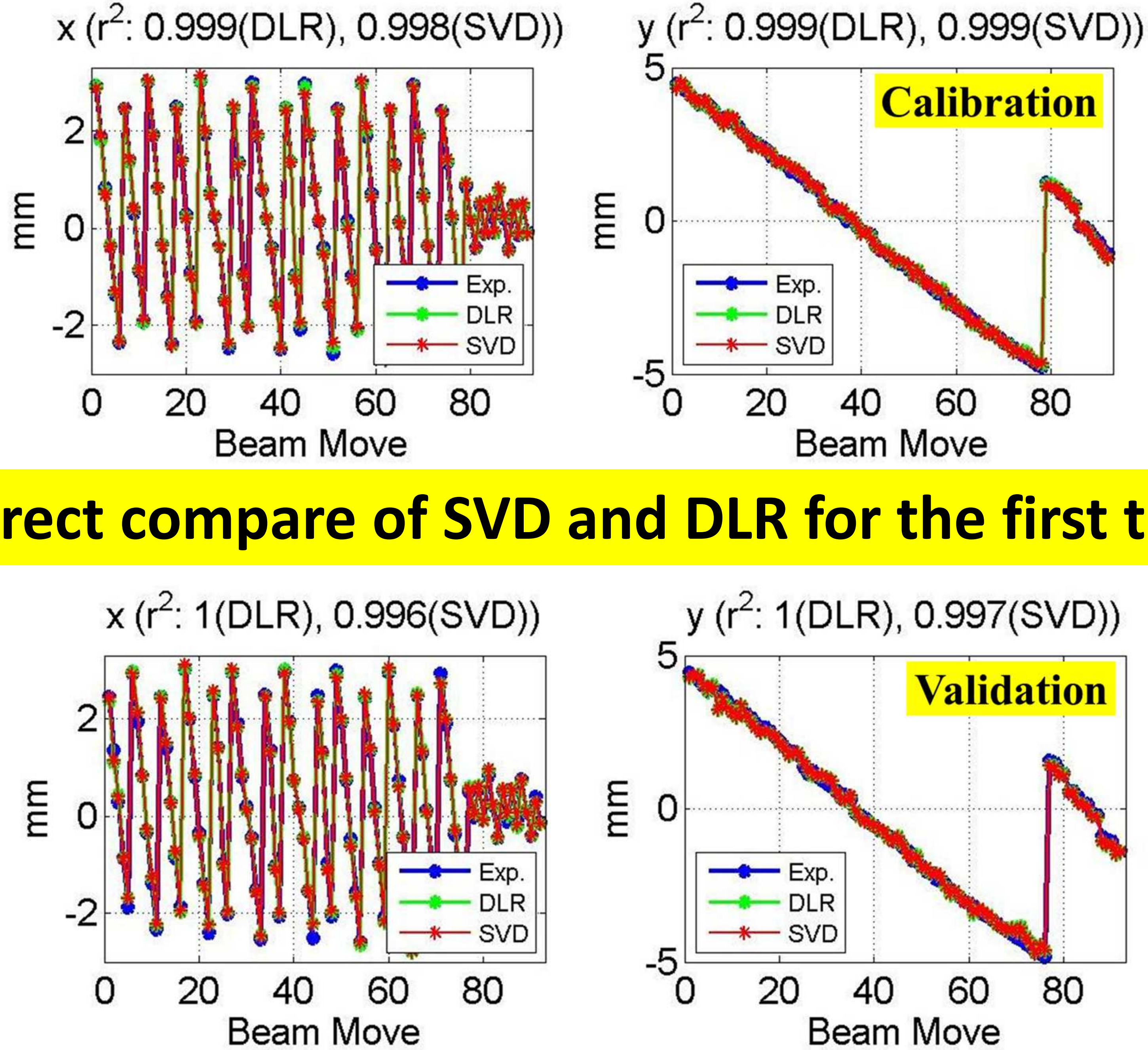


$$A_{reco} = \sum_{i=1}^{20} U_i \cdot S_{ii} \cdot V_i^T$$



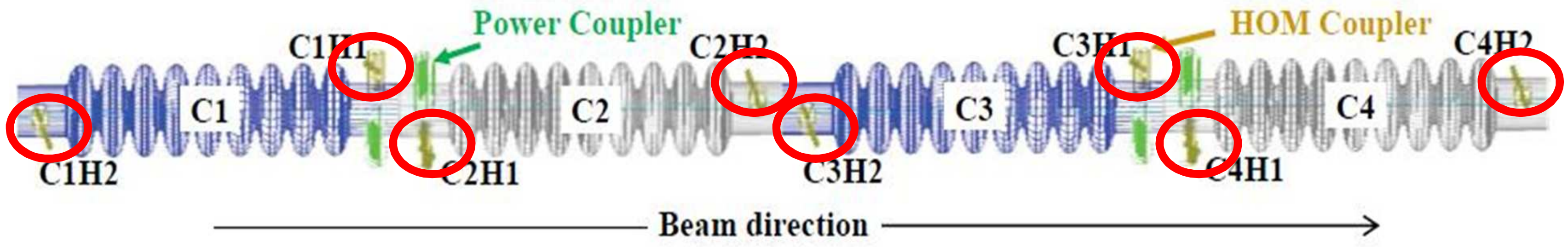
Dimension reduction

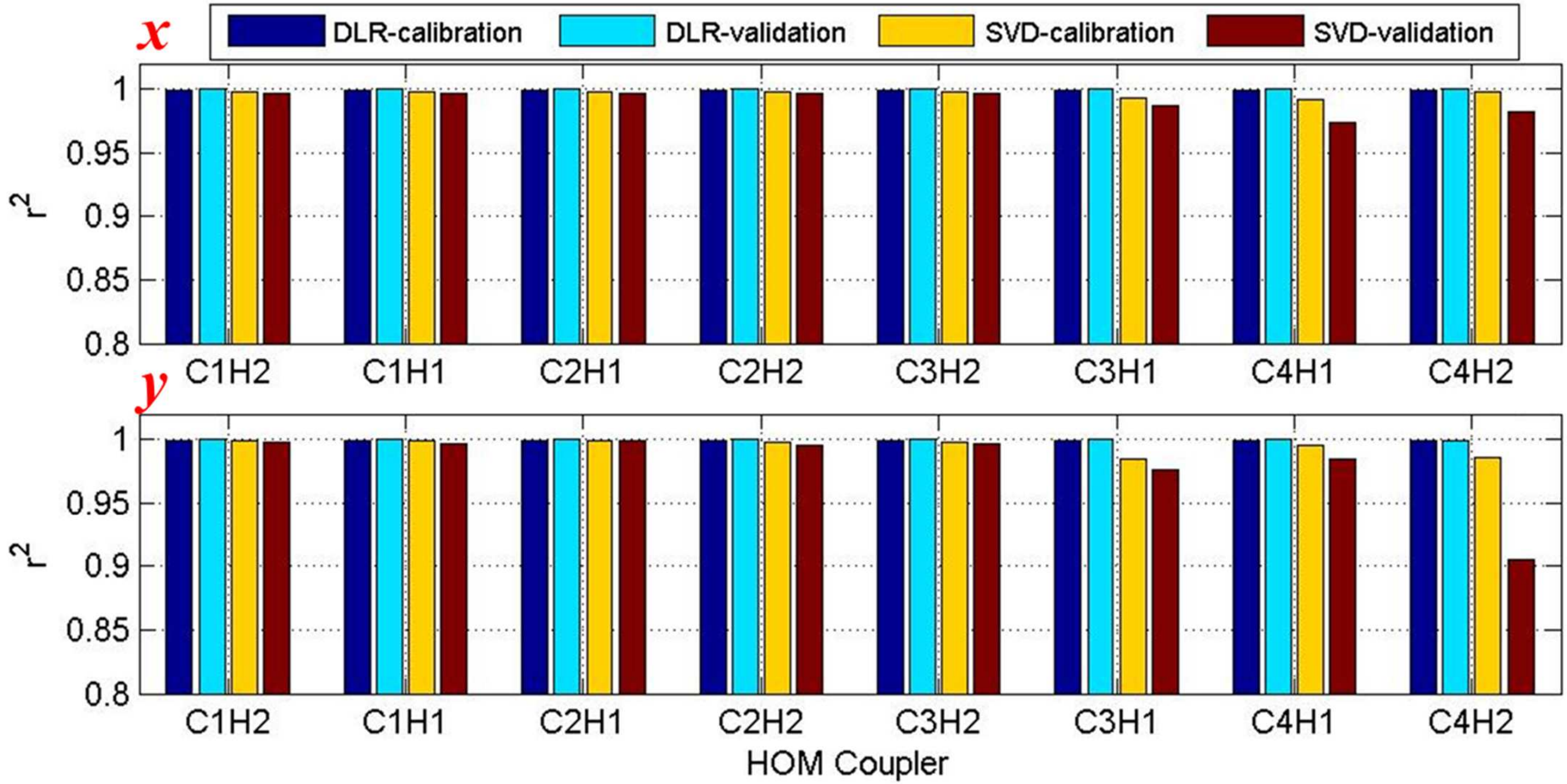
Performance (SVD)



Direct compare of SVD and DLR for the first time.

Extend to all 8 HOM Couplers





Summary

- **Trapped dipole modes** found in the 5th dipole band
- **Linear dependence** of HOMs on the transverse beam offset observed
- One mode to **a small band of modes**
- SVD and DLR are compared for **the first time**
- Dedicated electronics are under design by collaborations of DESY and Fermilab

Dipole Candidates	*f* range	Based-on
Beampipe modes†	~ 4 GHz	beam pipe
1st or 2nd cavity band†	~ 4-6 GHz	module
5th cavity band	~ 9 GHz	cavity

†P. Zhang, *et al.*, DIPAC2011, Hamburg, Germany, 2011, MOPD17

- A PRSTAB paper is in prepare on HOM diagnostics