Study of HOM-Based Beam Alignment in Third Harmonic SC Cavities at FLASH

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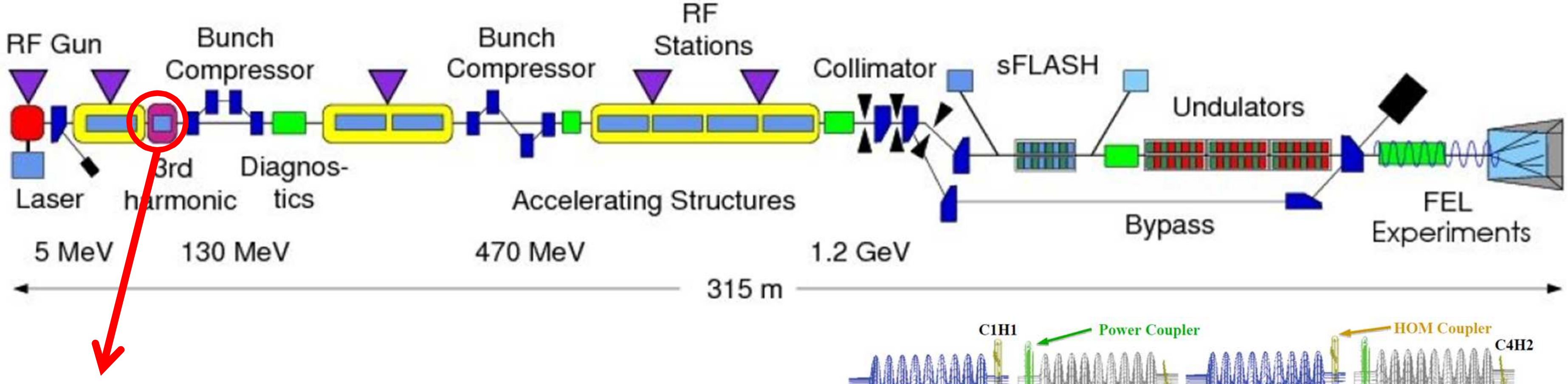
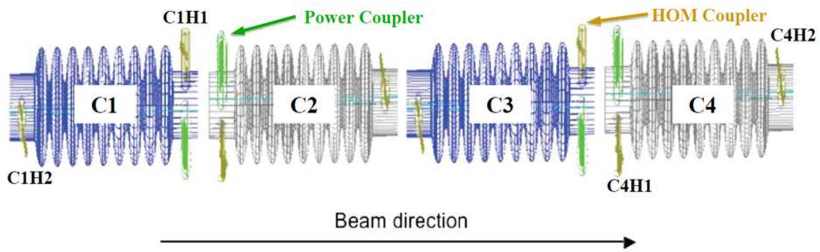
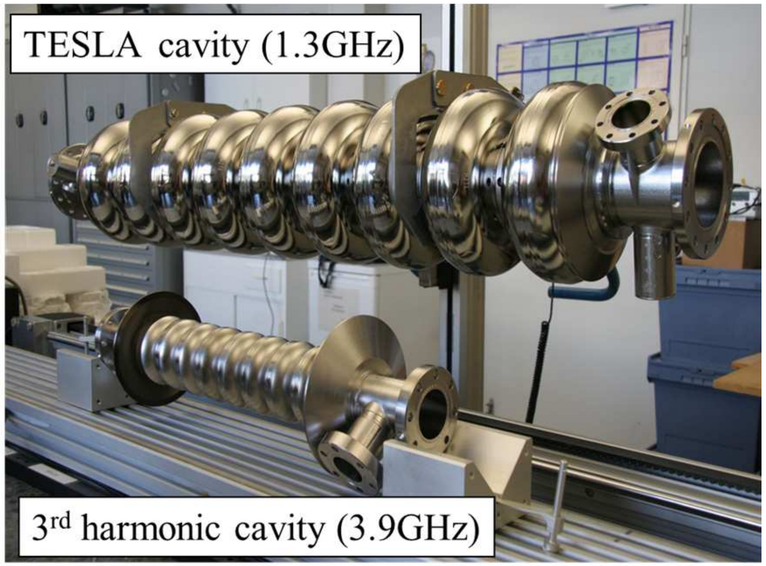
FLASH and ACC39

Free-electron LASer in Hamburg (FLASH)







Motivation

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

  - influence the beam both longitudinally and transversely

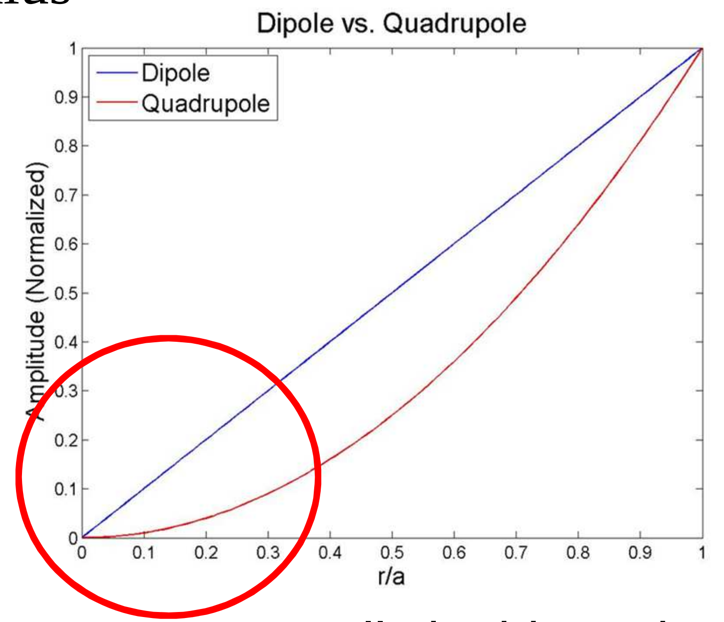
  - non-monopole modes excited by off-axis particle

- **Dipole modes dominate transverse wake potentials**

$$(Amplitude)_m \sim W_\perp^{\ m} \sim \left(\frac{r}{a}\right)^m$$

r: beam offset
a: iris radius

m=1, dipole; m=2, quadrupole



Normally in this region

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

  - align the beam to the electric center

  - monitor beam position (HOM-BPM)

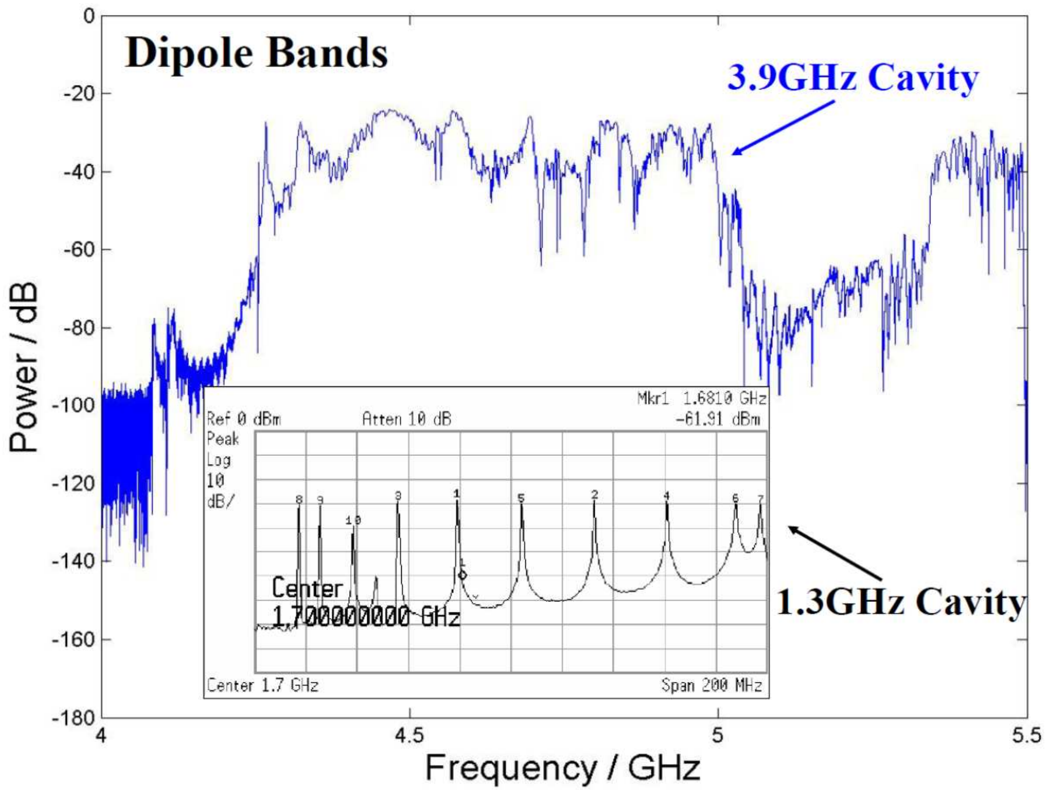
Principle proved in 1.3GHz Tesla cavity

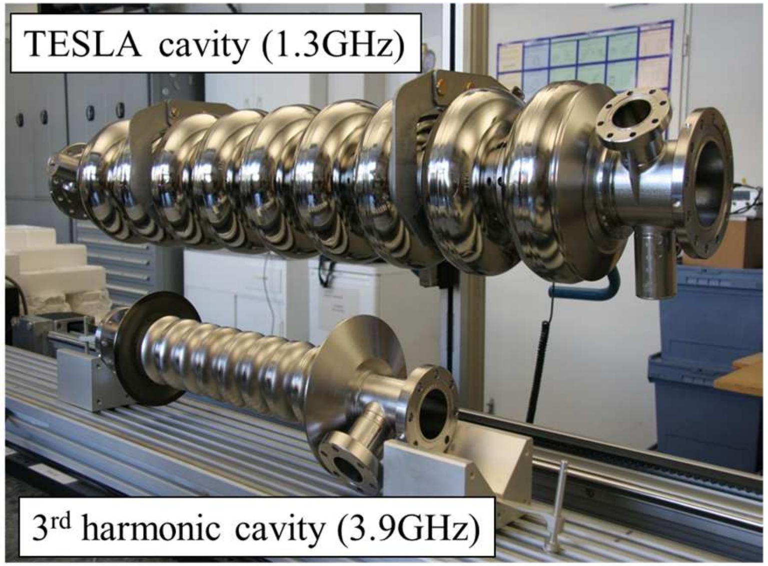
Motivation (Cont'd)

- Considerably larger wakefields (compare to 1.3GHz cavity)

$$w_{//} \sim \lambda^{-2}, \qquad w_{\perp} \sim \lambda^{-3} \qquad (\lambda \text{ is structure scaling factor})$$

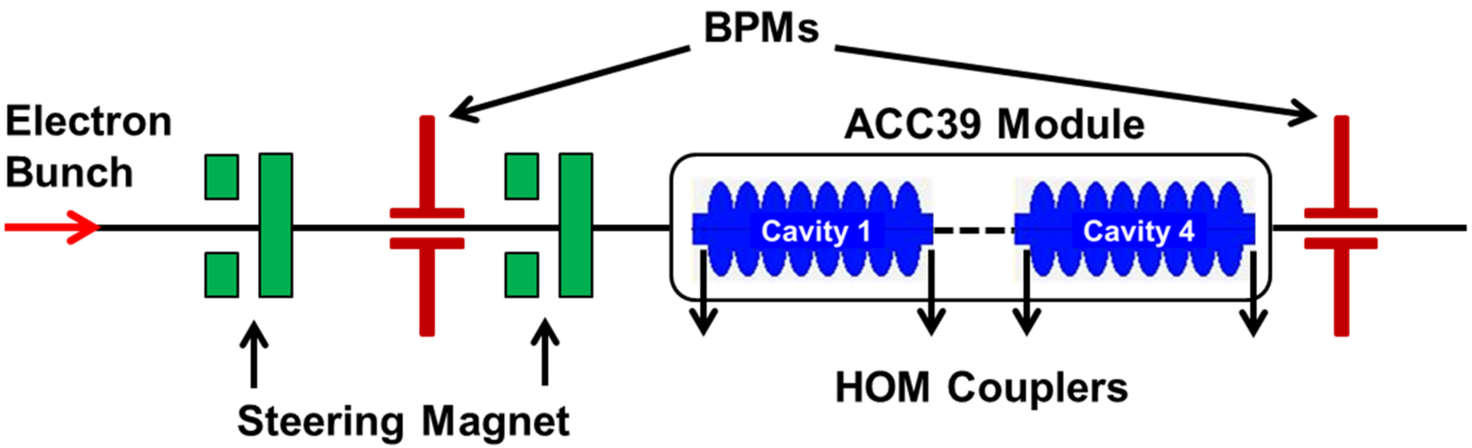
- HOMs propagate through attached beam pipes
- HOMs shift frequencies in ACC39 module w.r.t. single cavity and hard to identify

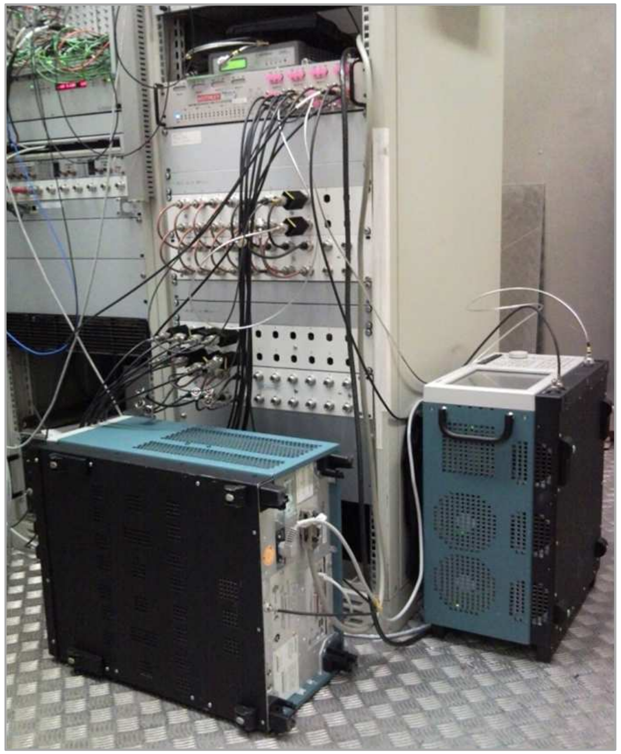


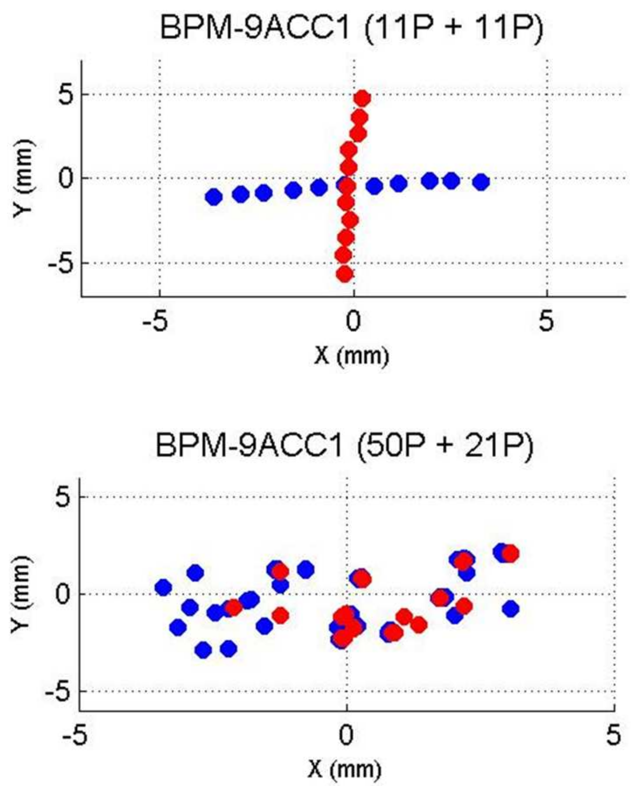


- 1.3GHz cavity
  multi-cell, single cavity modes
- 3.9GHz cavity
  multi-cavity modes

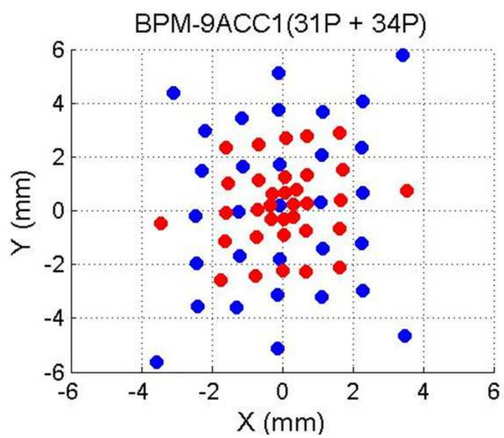
HOM Measurement



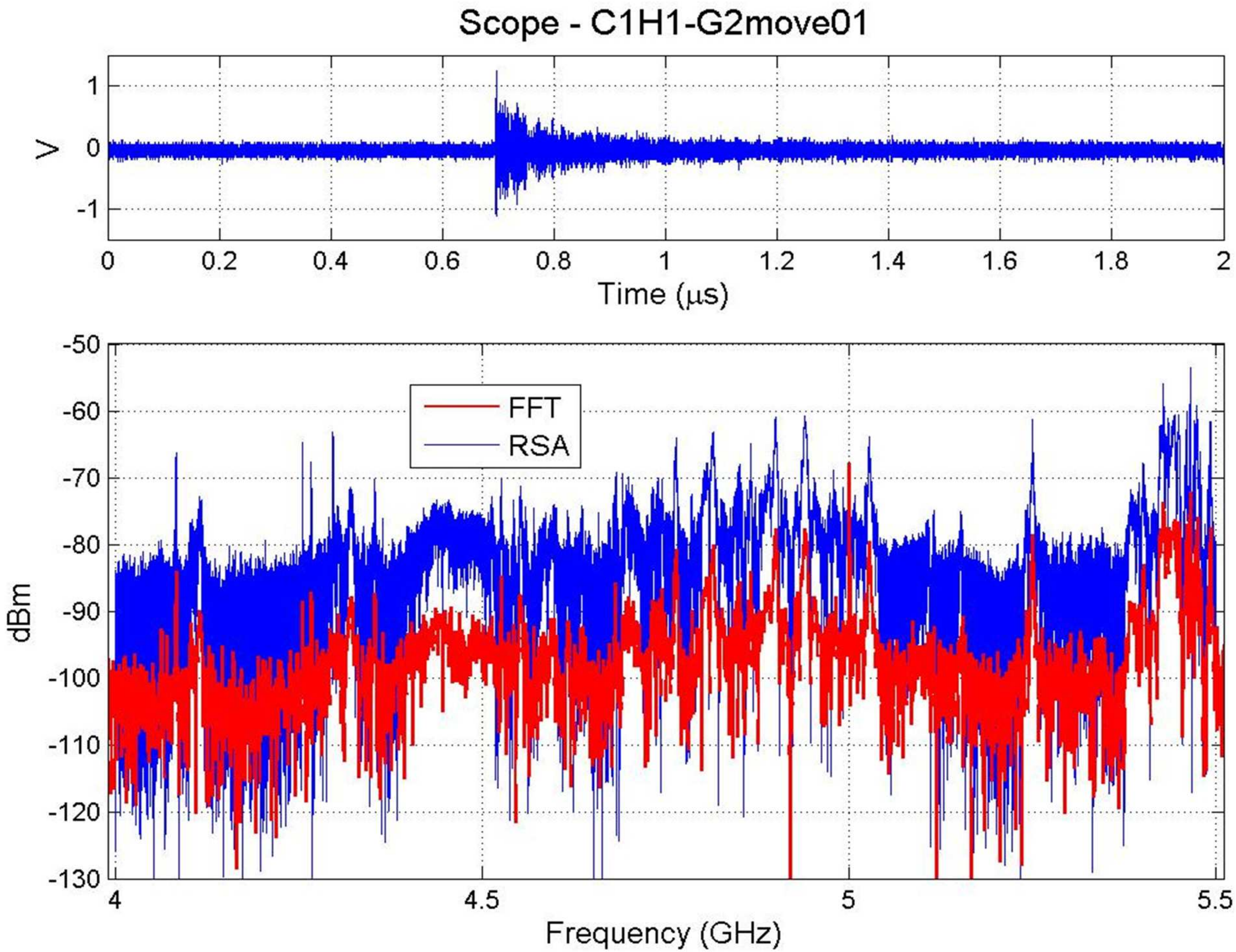




Steer the beam in various ways

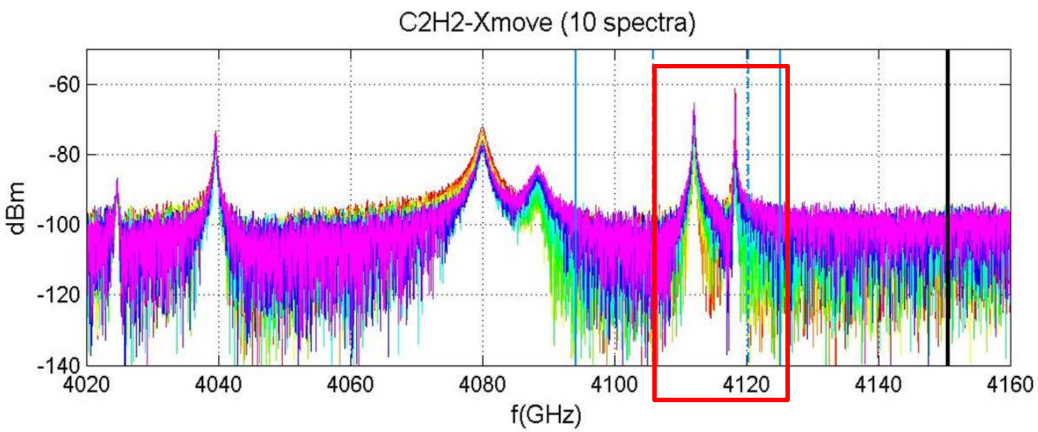


HOM Signal



Scope - C1H1-G2move01
V
1
0
-1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (μs)
dBm
-50
-60
-70
-80
-90
-100
-110
-120
-130
FFT
RSA
4
4.5
5
5.5
Frequency (GHz)

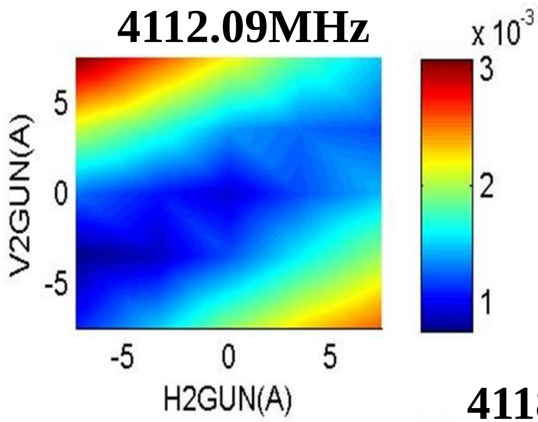
Dependence (Mode ID)



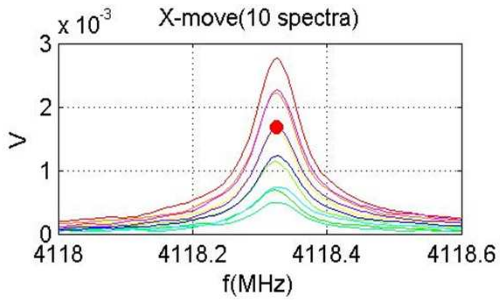
- **Lorentzian fit to get amplitude and *Q***

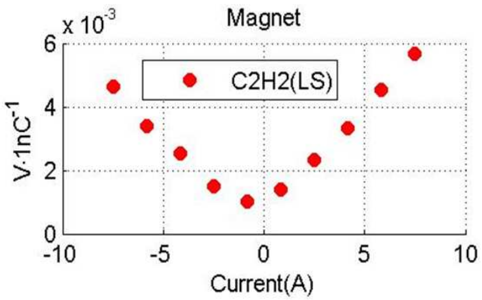
$$y = y_0 + A \cdot \frac{w^2}{(x - x_0)^2 + w^2}$$

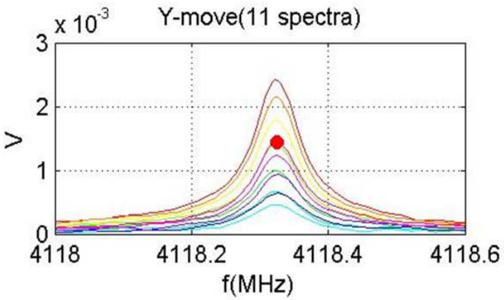
- **Power density of dipole modes**

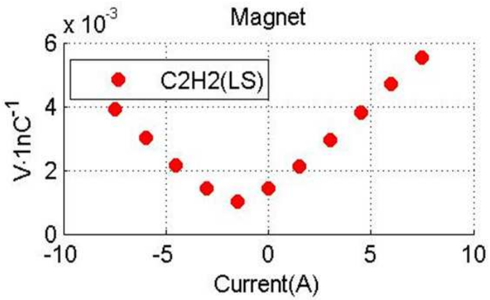


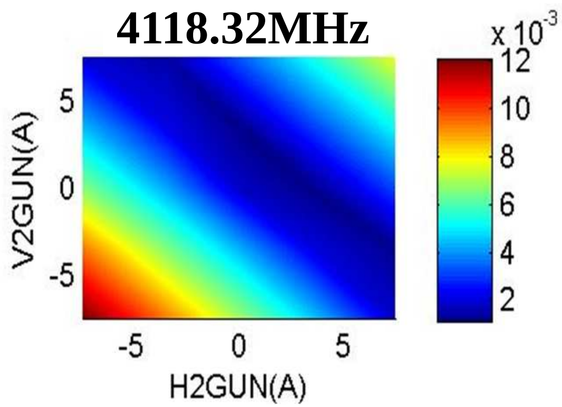
- **Dependence on beam movement**

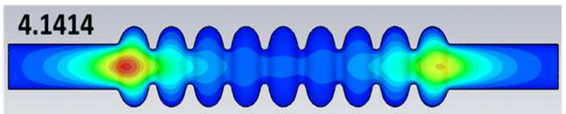


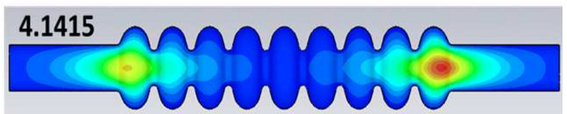




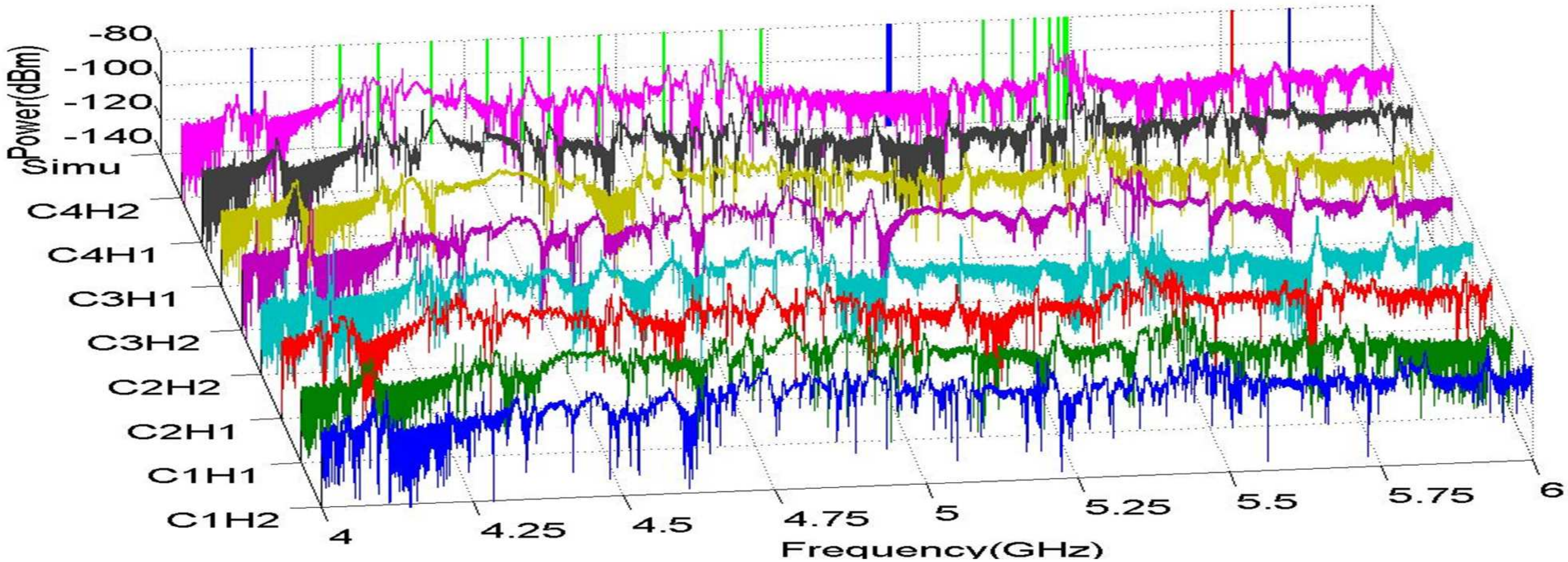


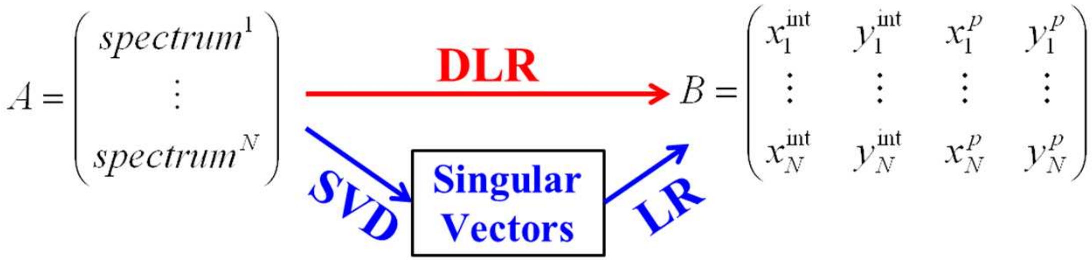






Alternative Methods





- **Direct Linear Regression (DLR)**

$$A \cdot M + B_0 = B$$

(size of *M* is too large)

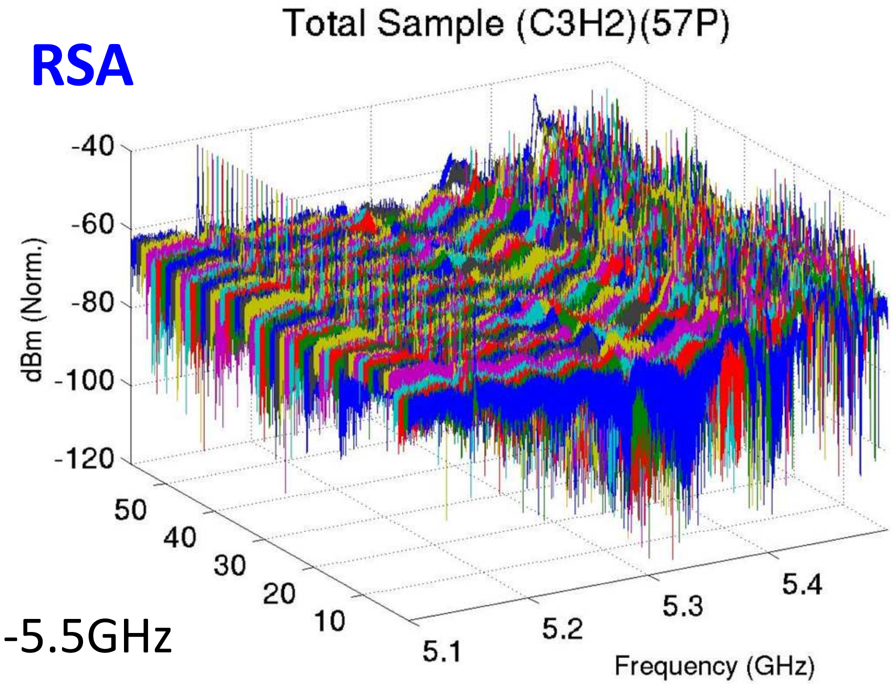
- **Singular Value Decomposition (SVD)**

$$A = U \cdot S \cdot V^T \longrightarrow A_S \text{ (small size)}$$

$$A_S \cdot M_S + B_{0S} = B \quad \text{(small size } M_S\text{)}$$

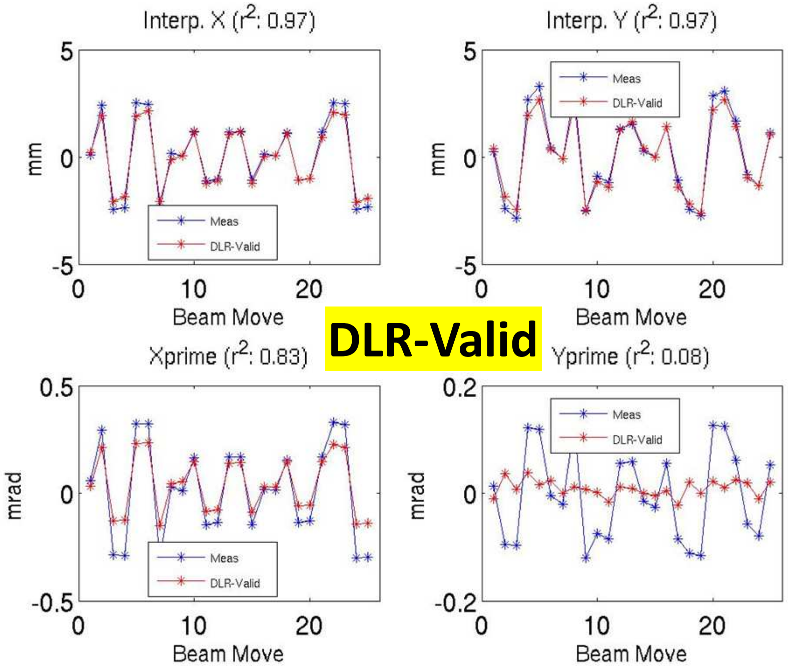
SVD vs. DLR

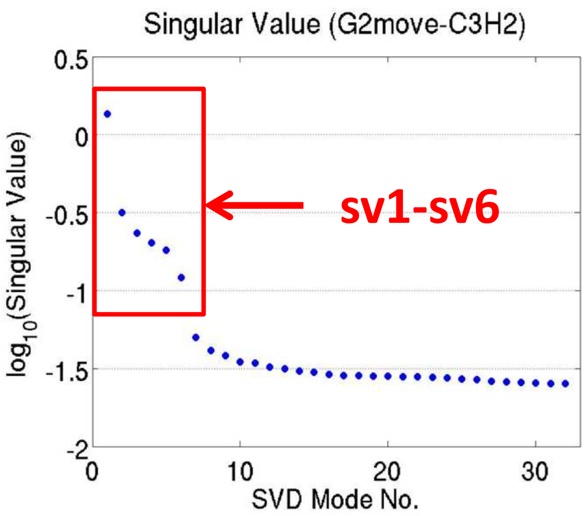
RSA



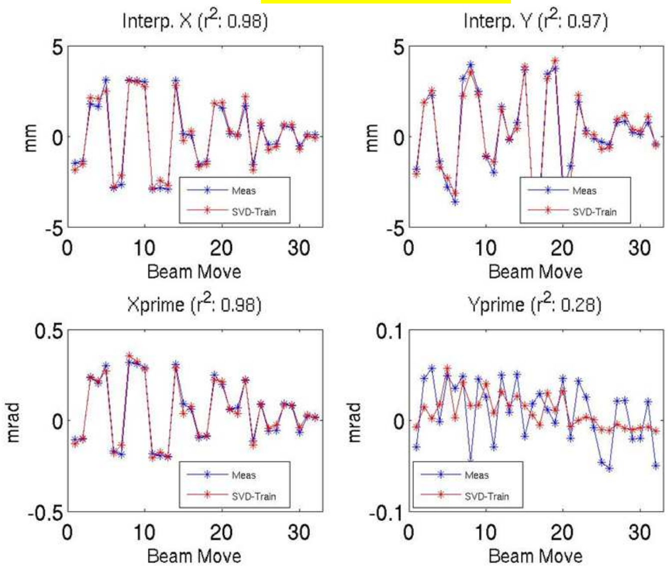
5.1-5.5GHz

DLR-Valid

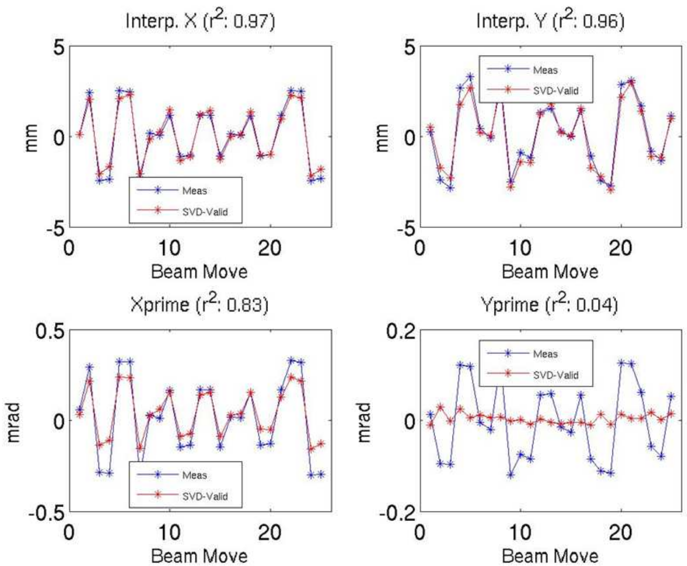




SVD-Train



SVD-Valid



Summary

- HOM dependence on beam movement firstly seen at the third harmonic cavity module
- Various different analysis methods show dipole dependence on beam movement

Future Plans

- Increasing the coverage in 4D space (x, y, x', y')
- Investigation of suitable modes for diagnostics electronics
- Design electronics for HOM-BPM for FLASH