Progress and Status of HOM based beam diagnostics for FLASH and the E-XFEL

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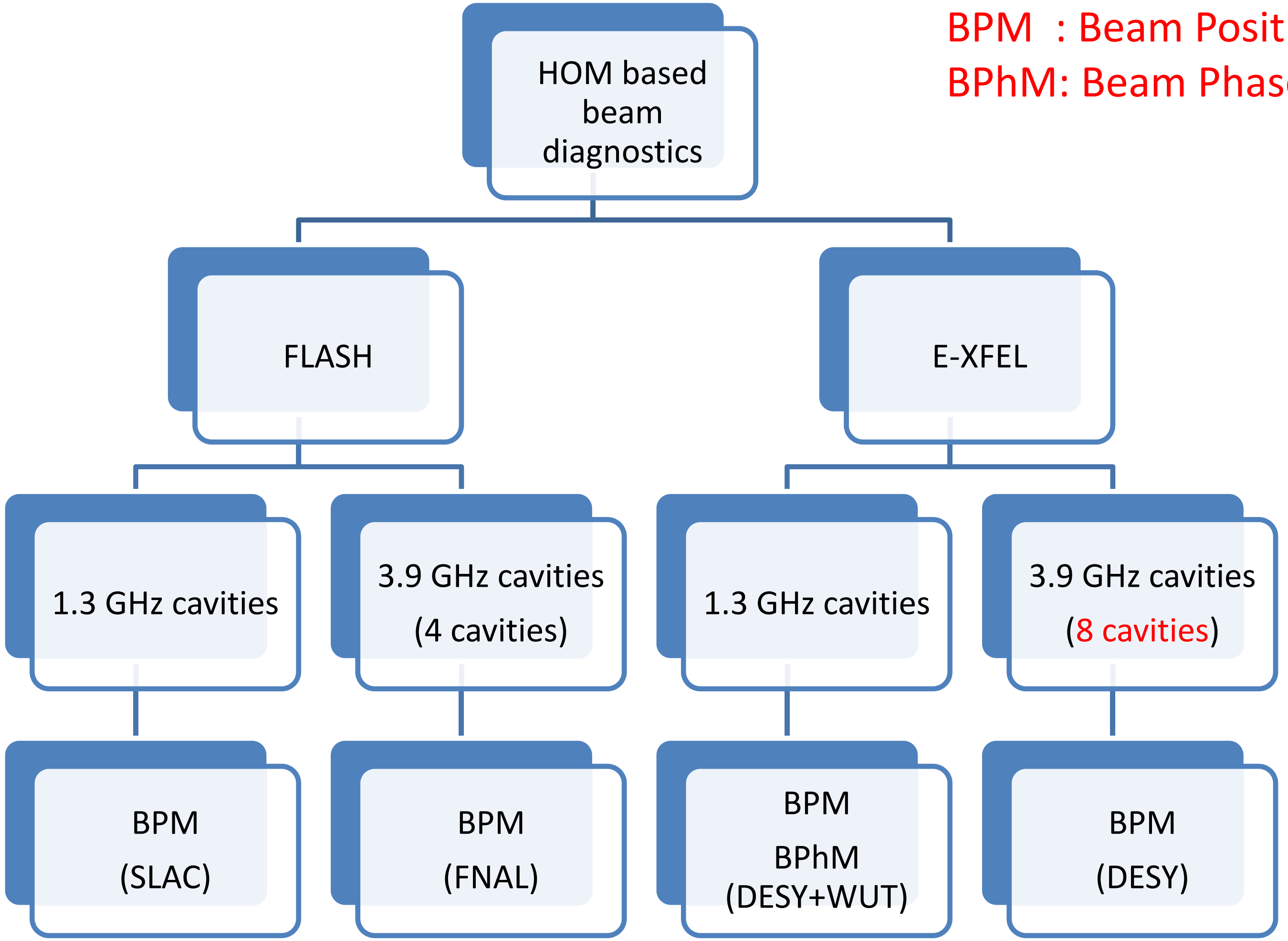
Outline

- Overview of Higher Order Modes based beam diagnostics
- Diagnostics at FLASH
- Diagnostics at the E-XFEL
- Summary and Outlook.

HOM based Beam Diagnostics – FLASH and the E-XFEL

BPM : Beam Position Monitor
BPhM: Beam Phase monitor



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  - HOMBPM for 1.3 GHz cavities
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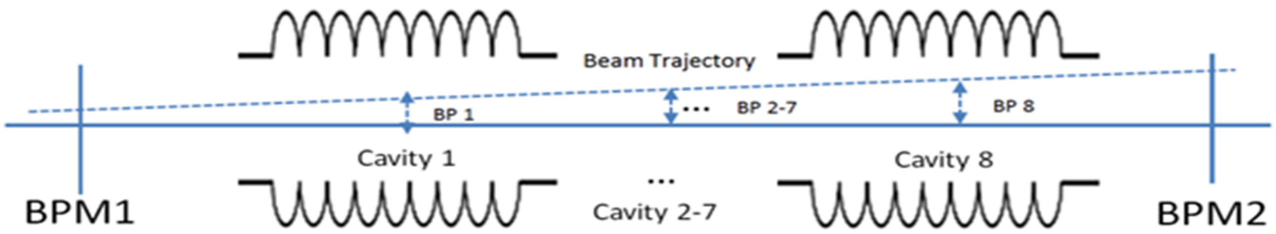
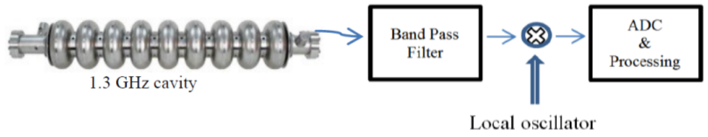
HOMBPM Review

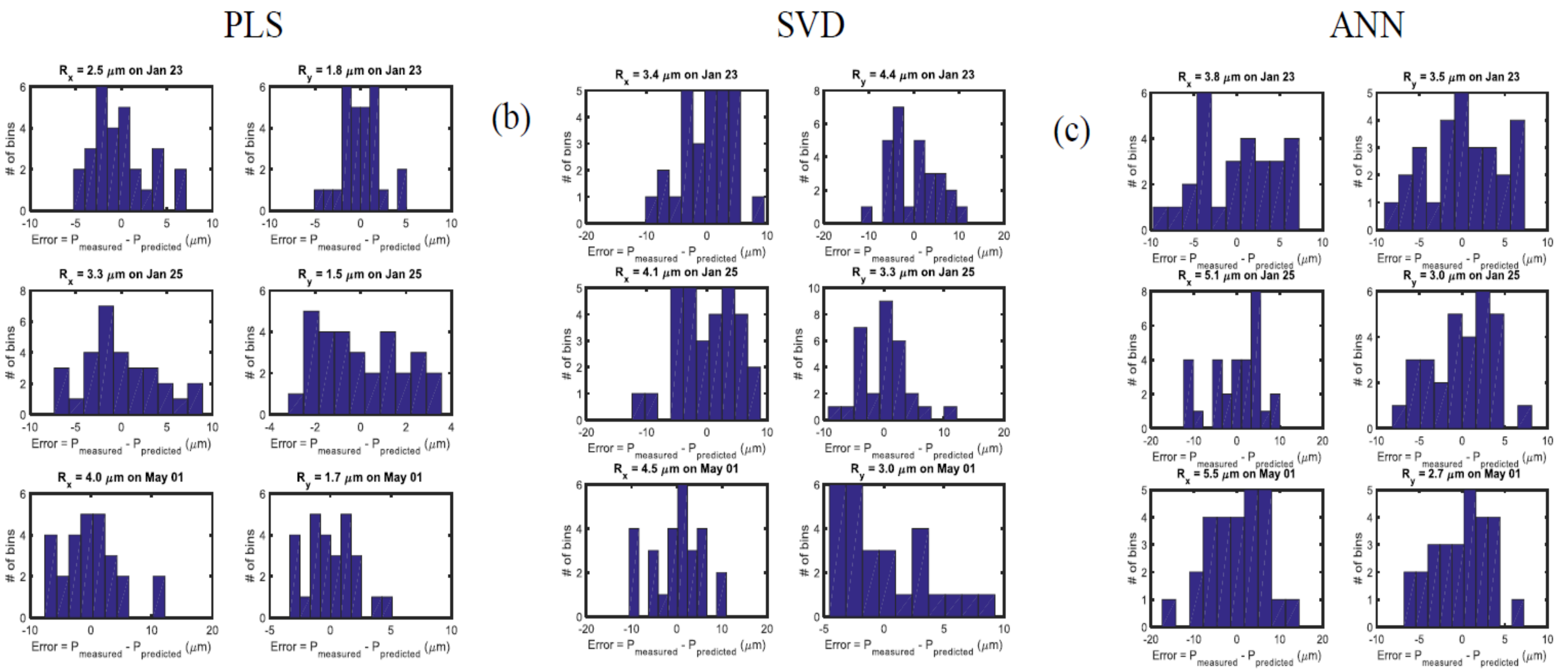




1. Beam position inside each cavity is interpolated from two BPMs.
2. Dipole signals are measured via each HOM port.
3. The correlation between dipole signal and beam positions can be established.

$$\begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} \\ \vdots & \vdots \\ C_{n1} & C_{n2} \end{bmatrix} = \begin{bmatrix} X_{11} & Y_{11} \\ \vdots & \vdots \\ X_{m1} & Y_{m1} \end{bmatrix}$$

HOMBPM at FLASH - 1.3 GHz cavities

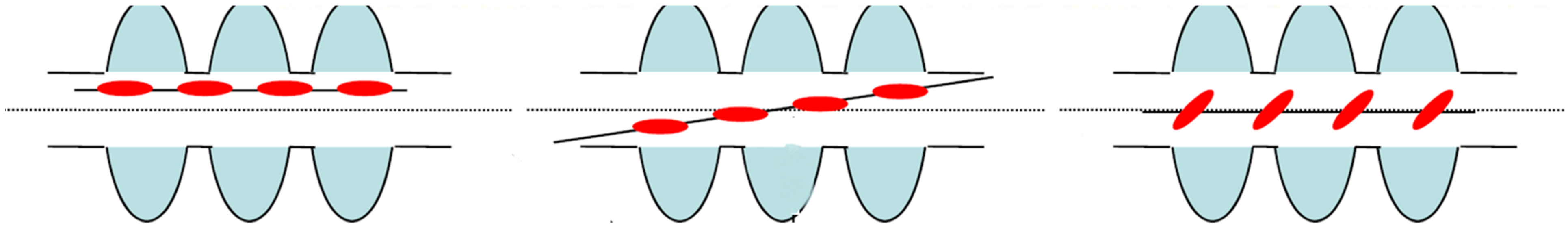


PLS: Partial Least Square
SVD: Singular Value Decomposition
ANN: Artificial Neural Network

Most of the results obtained are below 5 microns.

L. Shi *et al*, 2015, Stability and resolution studies of HOMBPMs for the 1.3 GHz superconducting accelerating cavities at FLASH, *Physics Procedia 77 (2015) 42-49*

HOMBPM at FLASH - 1.3 GHz cavities
Beam Excited Angular Wakefields



(a) Offset x   (b) Angle θ (c) Angle α

$$V_x(t) \propto x e^{-\frac{t}{\tau}} \sin(\omega t)$$

$$V_\theta(t) \propto -\theta e^{-\frac{t}{\tau}} \cos(\omega t)$$

$$V_\alpha(t) \propto -\alpha \sigma_z^2 e^{-\frac{t}{\tau}} \cos(\omega t)$$

- Scenario (b) can play an important role in beam position determination.
- For scenario (a) and (b), beam with 1 mm offset excites signal with the same amplitude as with 100 µrad angle.
- We are currently investigating the effects based on simulation and measurements.

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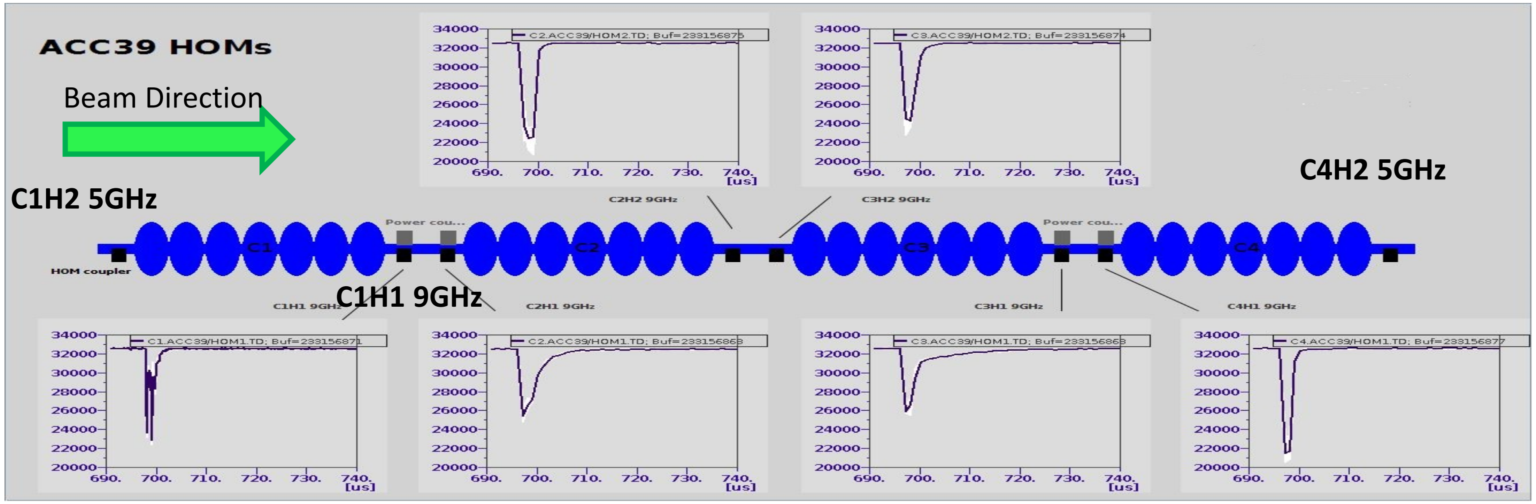
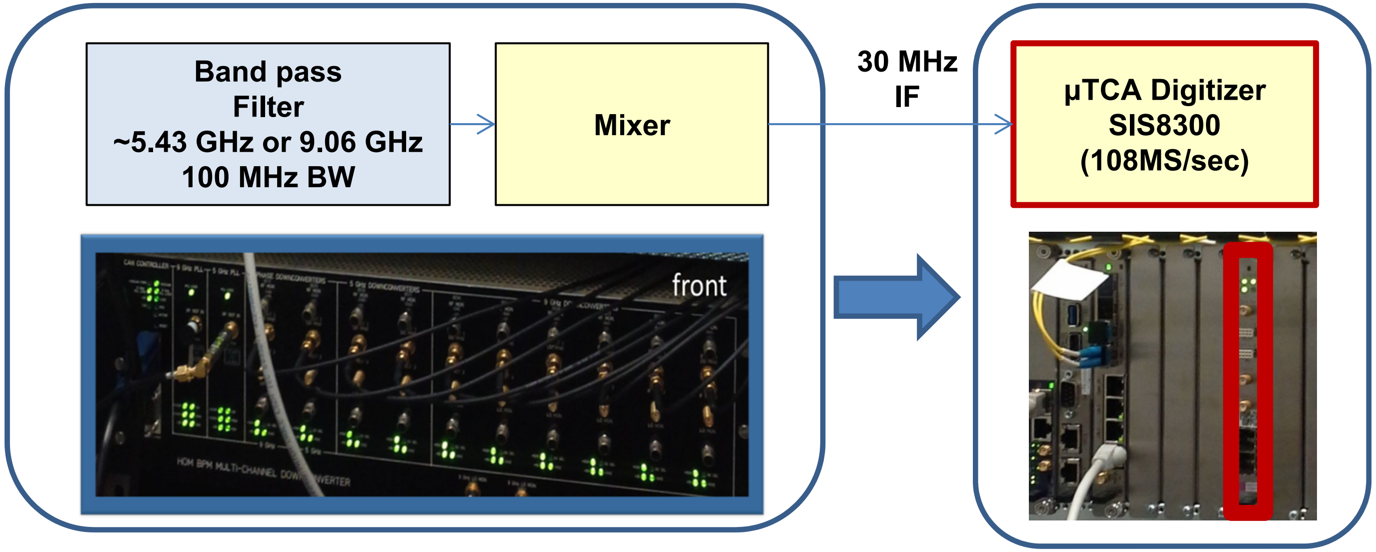
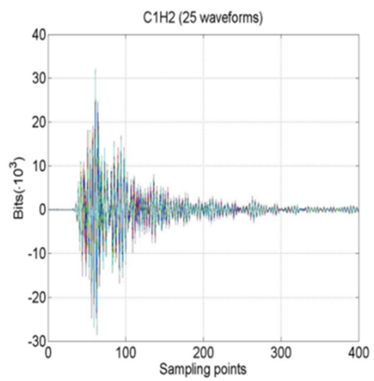
HOMBPM at FLASH – 3.9 GHz cavities







N. Baboi et al, TUPF06, IBIC14

HOMBPM at FLASH – 3.9 GHz cavities

- The analysis methods of the HOMBPM for 1.3 GHz cavities were applied to the 3.9 GHz cavities. But the results obtained so far are not acceptable.

  Example:

  Results summary of C1H2 (5 GHz)

	Time domain		Frequency domain	
(x, y) (μm)	SVD	PLS	SVD	PLS
Training (19th of August)	(38,60)	(32, 16)	(42,77)	(8,28)
Validation (19th of August)	(304,257)	(309,206)	(438,242)	(451,473)
Validation (3rd of August)	(1090,1640)	(1240,4470)	(695,455)	(697,629)

  – The calibration (training) and validation are separated by only ½ hour.
  – This may result from the phase instability and also the spectra variation over time.
  – The parameters of the electronics are not properly set.

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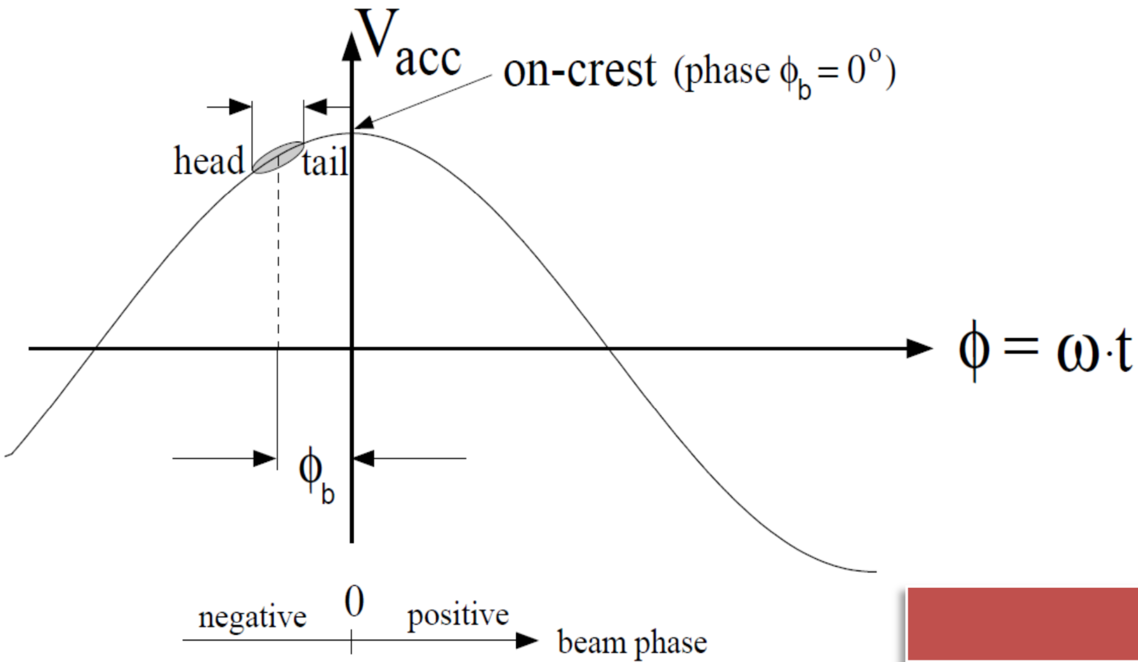
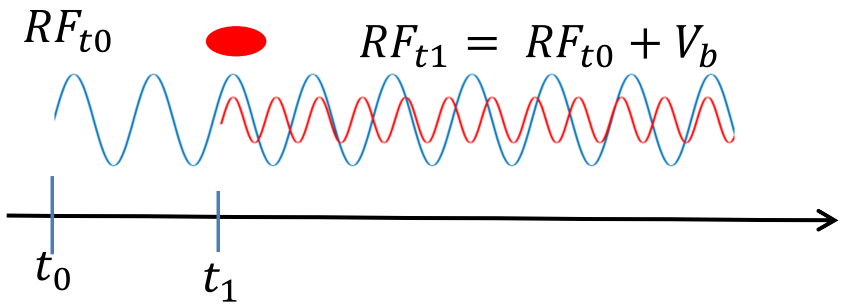
Field Control inside cavity

- FEL operation requires high stability of amplitude and phase.

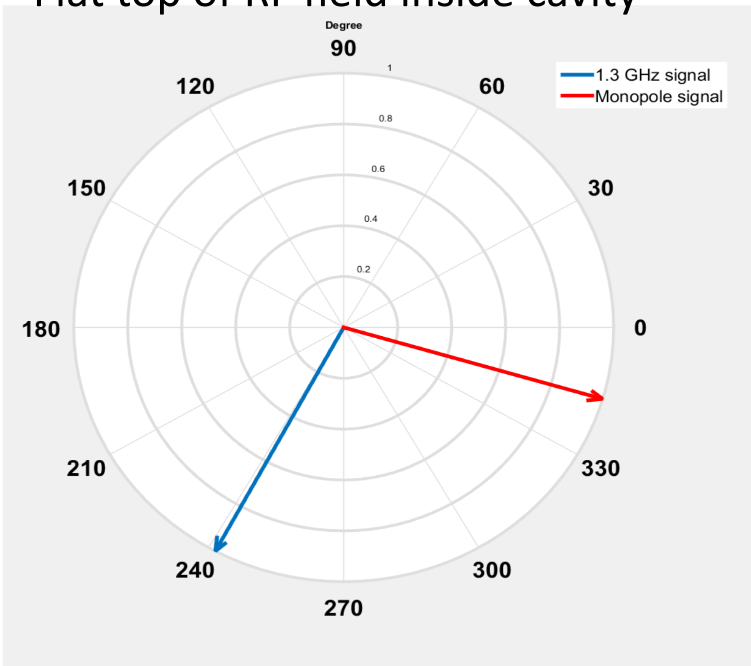


	Amp	Phase
FLASH	0.1%	0.1 degree
E-XFEL	0.01%	0.01 degree

How to determine the beam phase



Flat top of RF field inside cavity



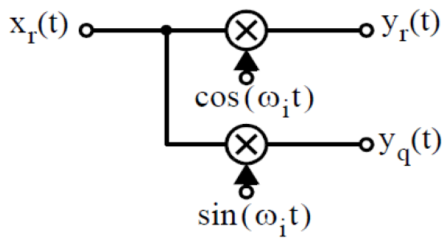
RF_{t0}: $1.3\ GHz\ signal$

V_b: $\sim 2.4\ GHz\ beam\ induced\ signal$

RF_{t1}: $1.3 + 2.4 GHz\ signal$

- The absolute angle spanned by RF_{t0} and V_b is not directly measureable.

- Assume: $x_r(t) = \sum_{i=1}^{N} \cos(\omega_i t + \varphi_i)$



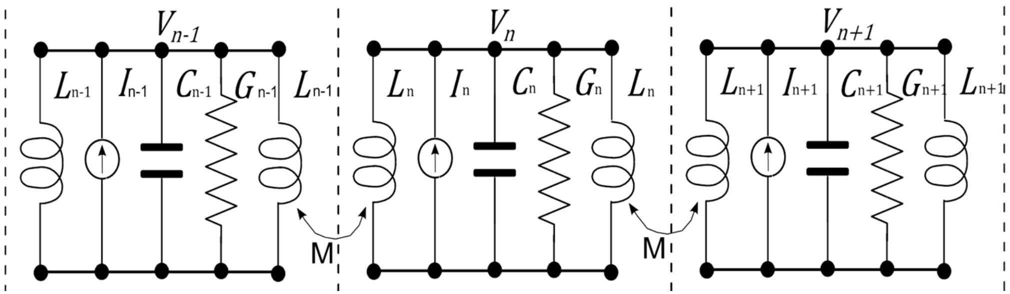
$$y_r(\mathrm{t}) = \frac{\cos(2\omega_i t + \varphi_i) + \cos(\varphi_i)}{2}$$

$$y_q(\mathrm{t}) = \frac{\sin(2\omega_i t + \varphi_i) + \sin(-\varphi_i)}{2}$$

$$\Rightarrow \tan(\varphi_i) = \frac{\int y_q(\mathrm{t})dt}{\int y_r(\mathrm{t})dt}$$

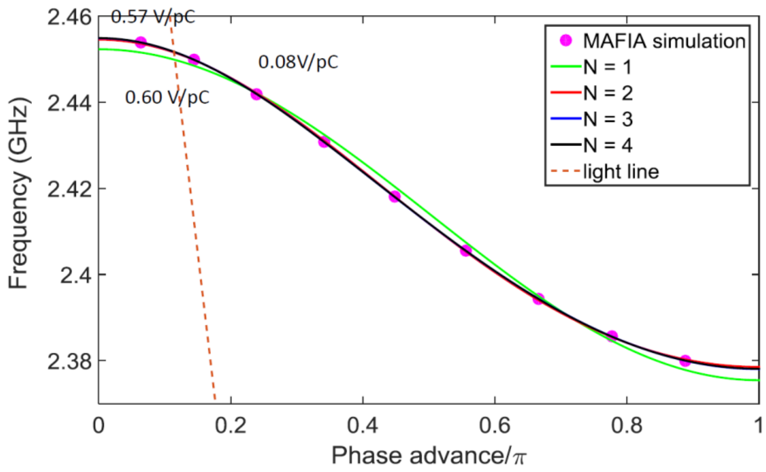
Beam Phase Monitor for 1.3 GHz cavities – Circuit model

- Single chain of coupled parallel RLC circuit was used to facilitate the beam phase monitor development.

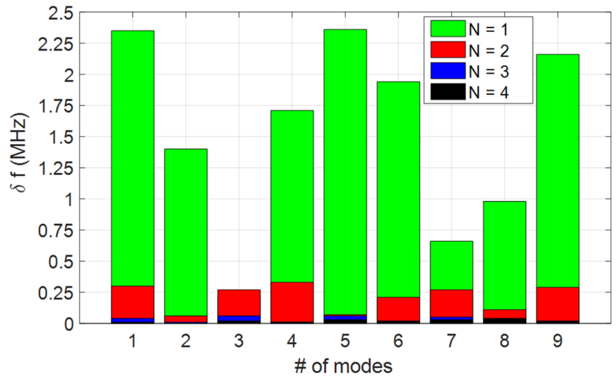


Nearest neighbor: N = 1
Next nearest neighbor: N = 2
Next next nearest neighbor: N = 3 …
Ø: Phase advance

Dispersion relation



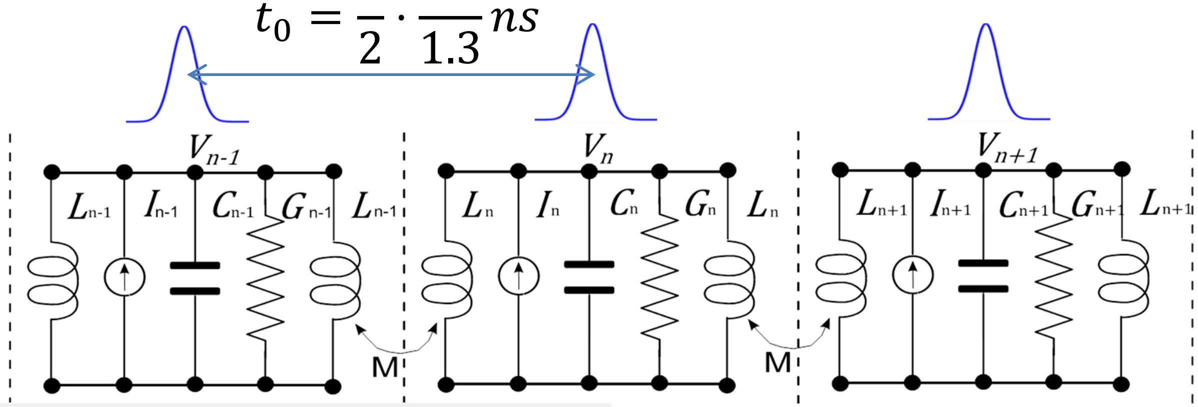
|CM – MAFIA|

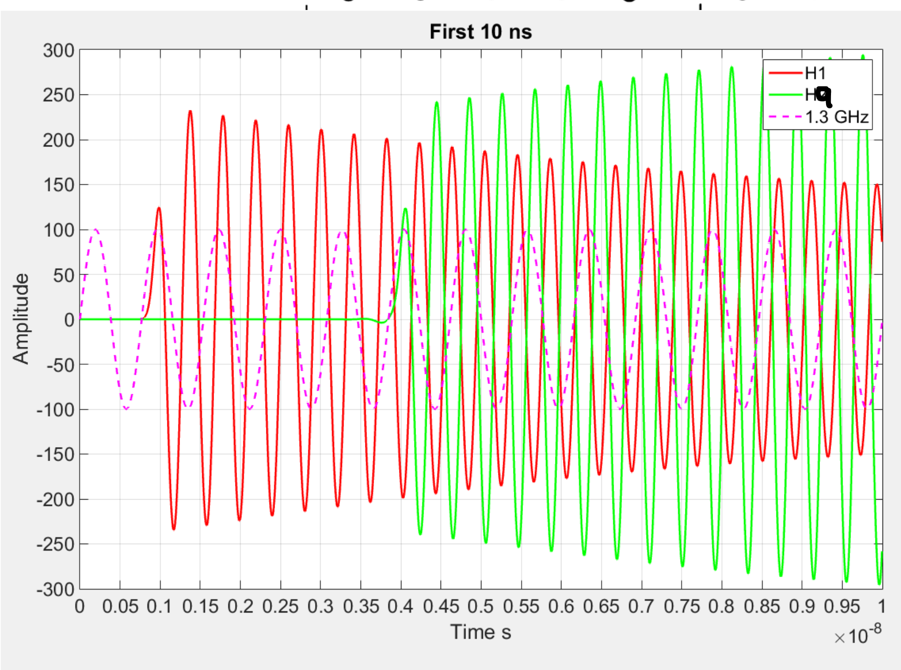


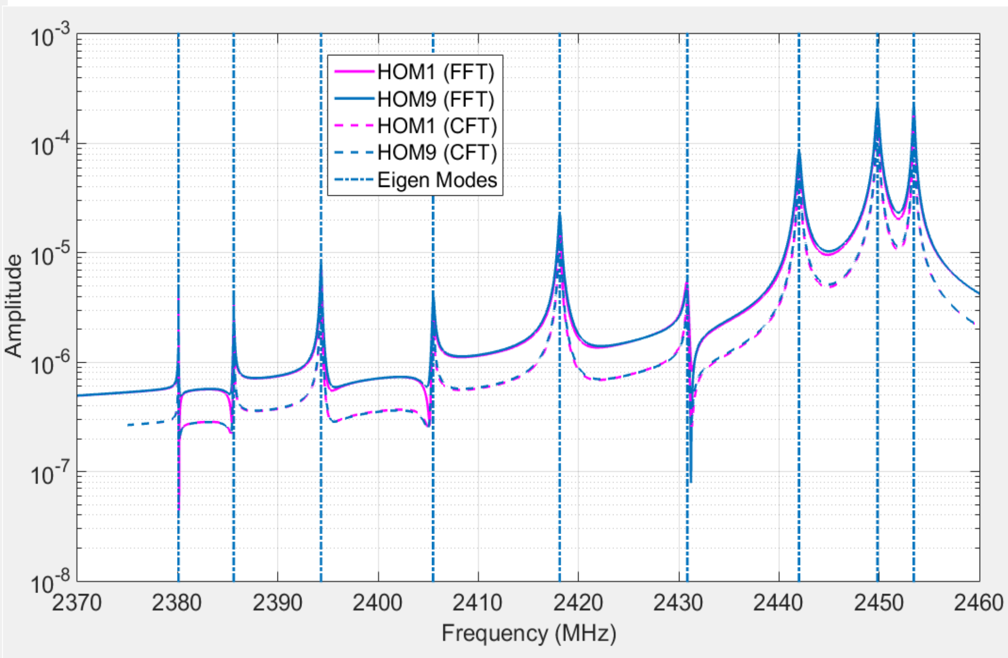
$$\omega^2=\omega_r^2\left(1-\sum_{1}^{N} k_n\cdot \cos(n*\emptyset)\right)$$

Voltage Waveforms at cell 1 and 9

$$t_0 = \frac{1}{2} \cdot \frac{1}{1.3} ns$$

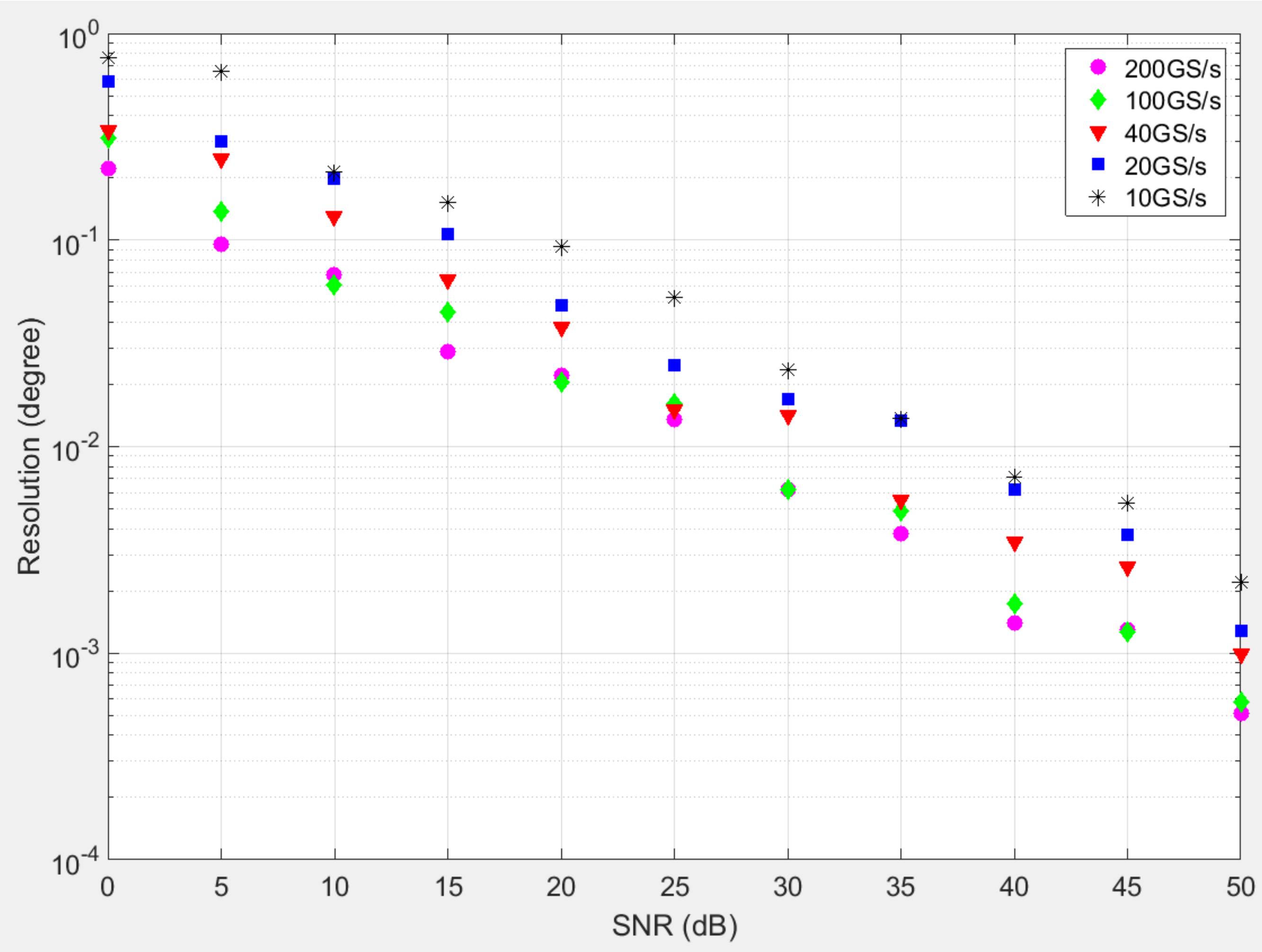






50 µs long waveform

Beam Phase Monitor - Circuit model

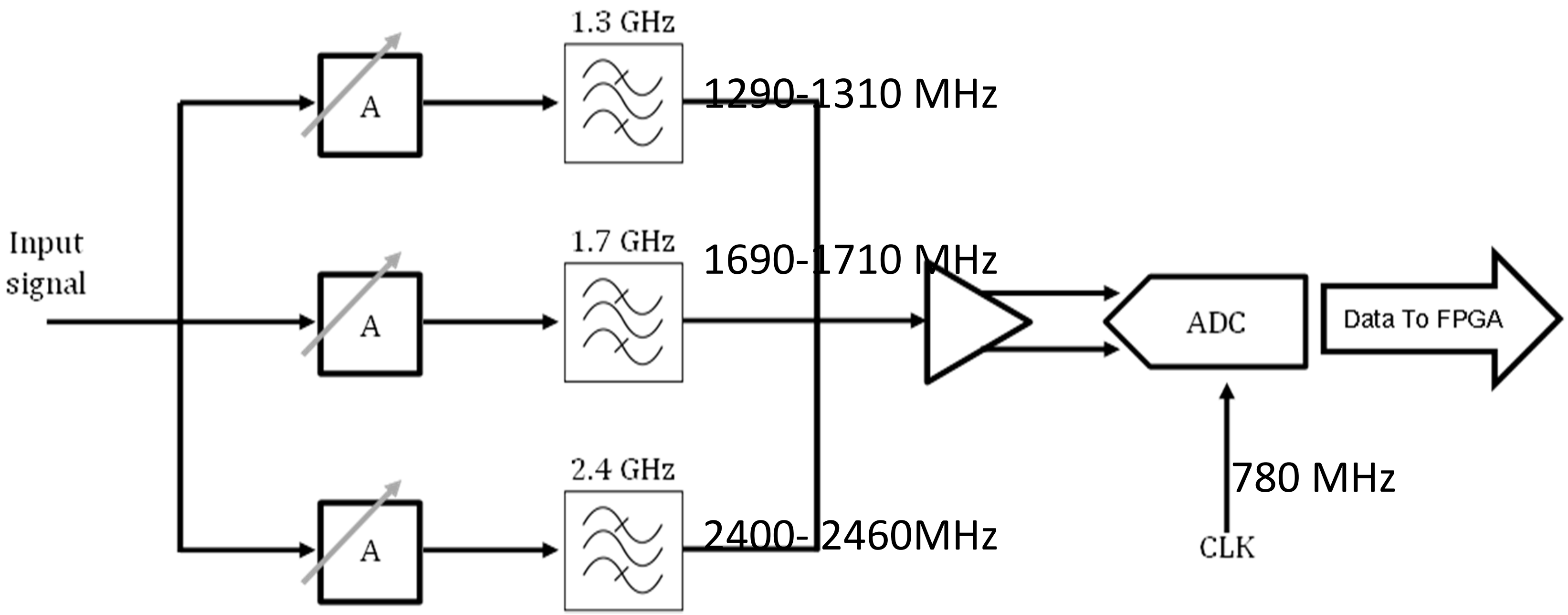


1. By increasing SNR, resolution can be improved.

2. The resolution also depends on the sampling frequency.

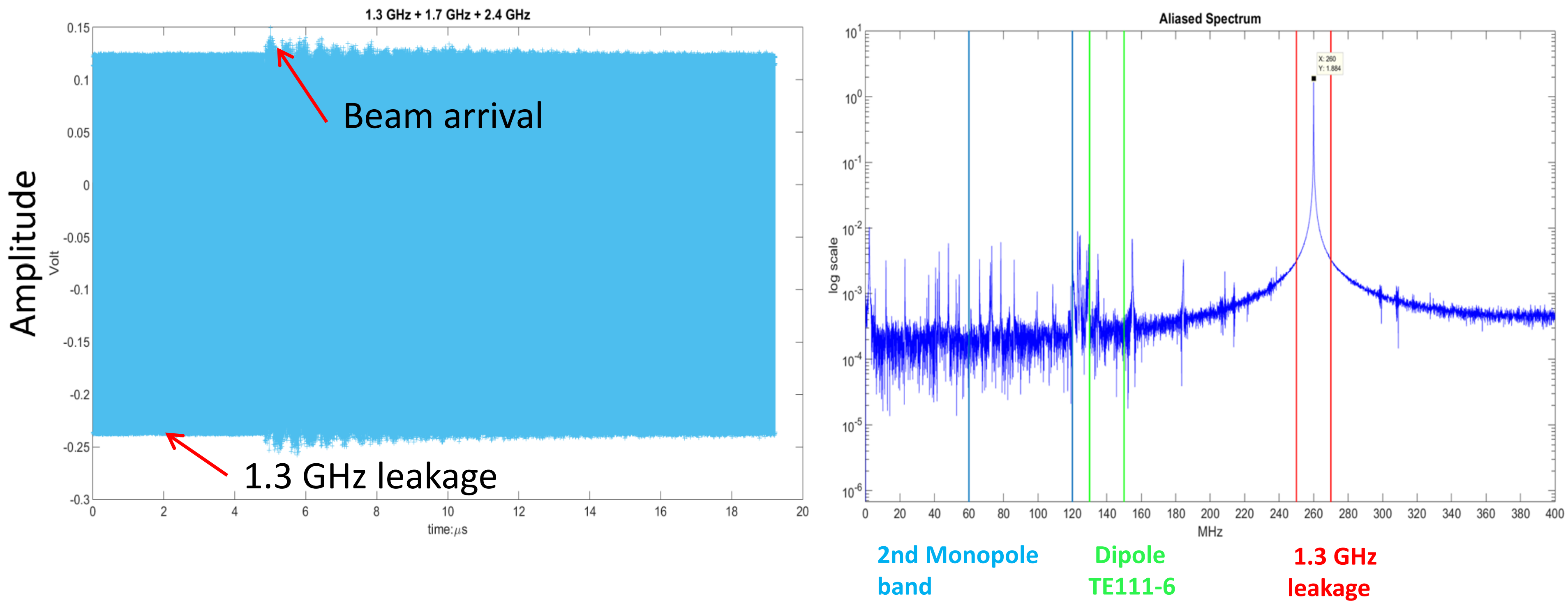
Note: SNR is varied by keeping signal power fixed and varying noise power. Alternative way exists!

Electronics of HOM based beam Phase measurements



Signal can be aliased to 250-270 MHz (fundamental Monopole), 130-150 MHz (Dipole), 60-120 MHz(2nd monopole band) respectively.
The final electronics will be based on different sampling frequency .

Example of outputs of test electronics

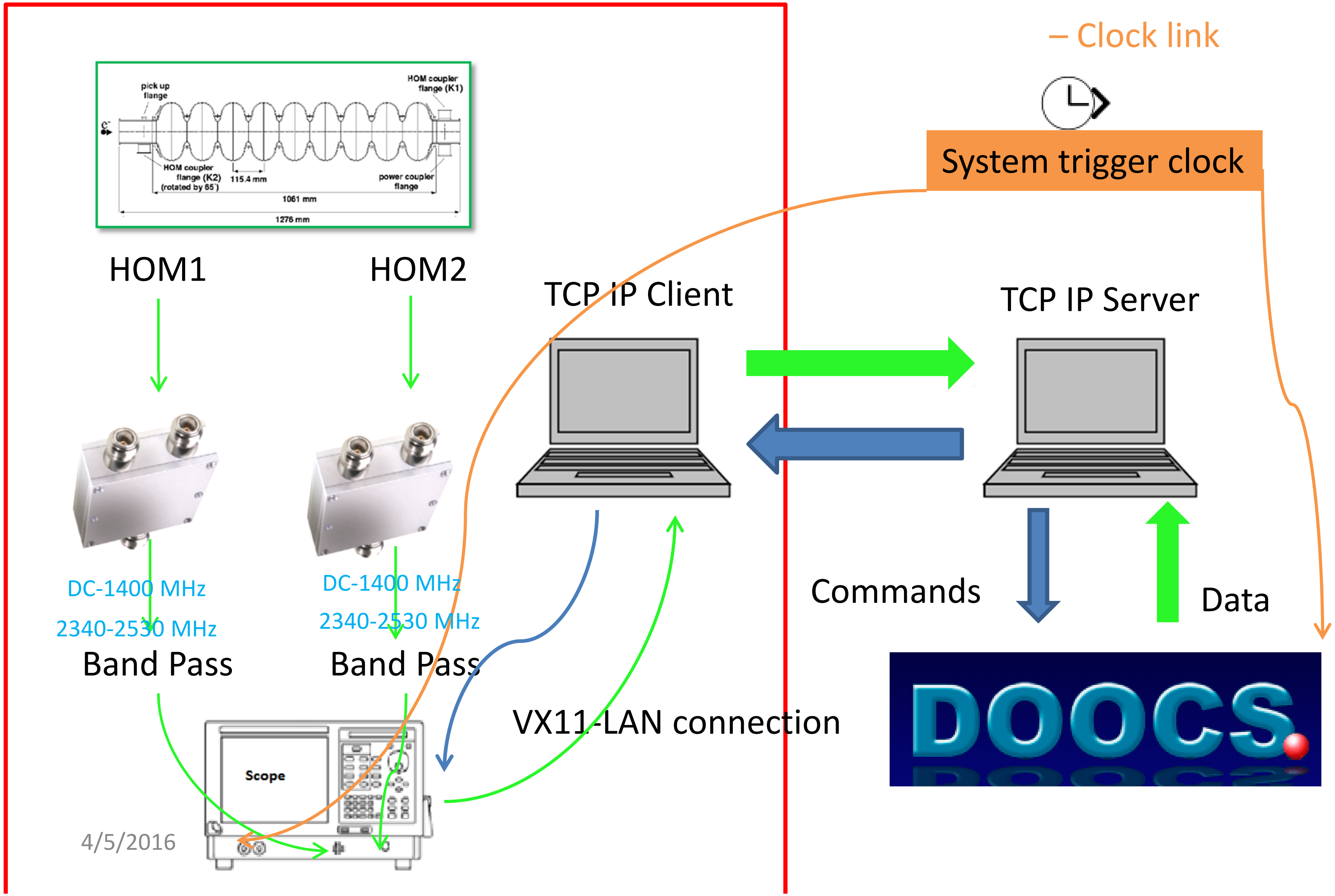


Clearly, attenuation or amplification for each channel needs to be matched with each other. (Sampled at 780 MHz)

Measured by Mr. Samer

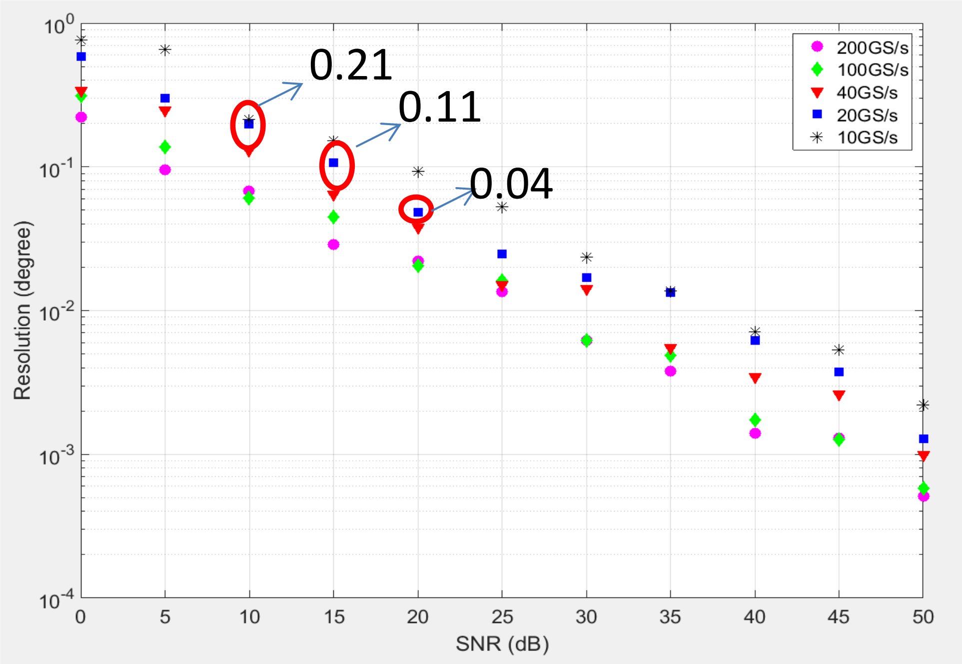
Setup for the beam phase measurements

– Data link
– Command link
– Clock link



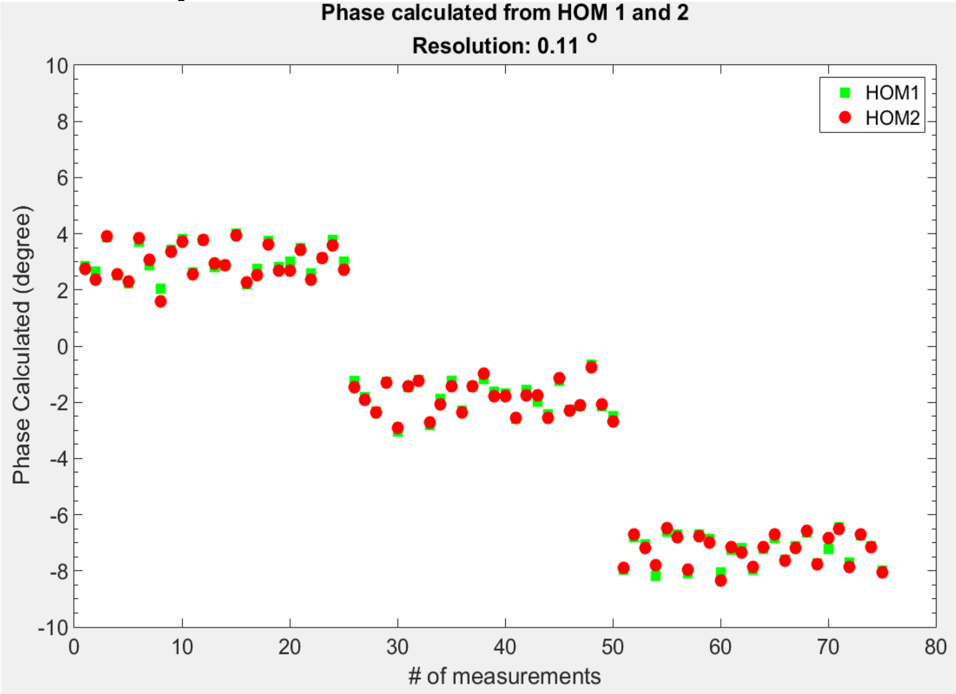
Beam Phase Monitor for 1.3 GHz cavities - Results

- Simulation (200 GS/s)



Estimation of SNR from scope shows it is between 10 and 20 dB.

- Experiment（20 GS/s）



Phase change -5 to 5 degree from Klystron. Resolution is about 0.1 degree.

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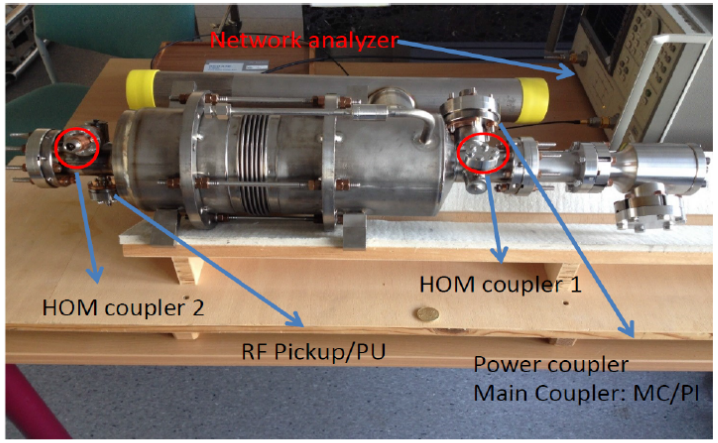
HOM Spectra measurements and characterization

- The spectra of 3.9 GHz cavities are more complicated than the 1.3GHz cavities.-> single dipole mode filtering is impossible [1].
- Which part of dipole spectra can be used for the beam position monitoring. ->Electronics specification
- Is the selected band of spectra stable over time?

[1]. P. Zhang Beam Diagnostics in Superconducting Accelerating Cavities, Springer Theses. Springer International Publishing; 2013.

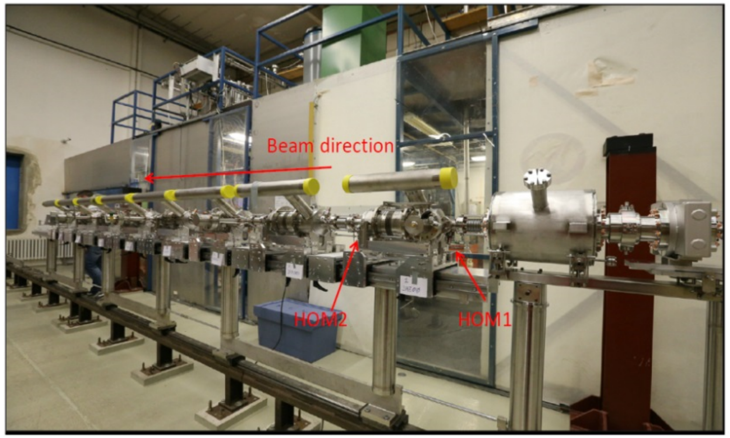
E-XFEL: S21 measurements for single cavity

- One VNA (HP8720C), Laptop, GPIB to USB adapter, 1 pair meters long RF cable.



The scan step is around 5 KHz

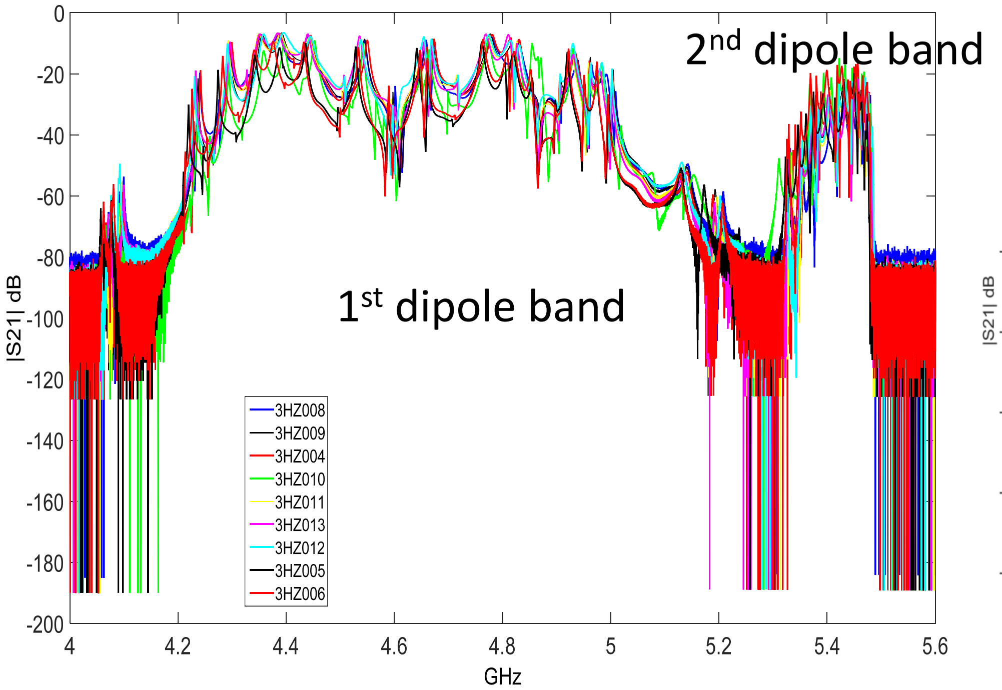
Single cavity measurements vacuum state, in room temperature

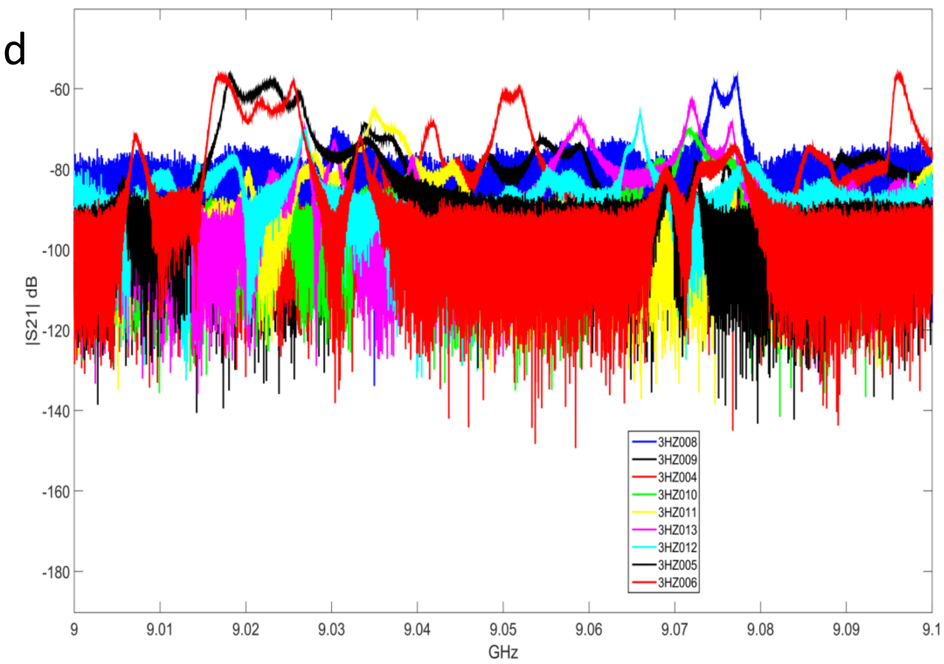


Coupled cavity measurements filled with Argon, at ~293K. Couplers are not terminated.

E-XFEL: S21 measurements for single cavities at 293K

- 1st and 2nd dipole band
- 5th dipole band

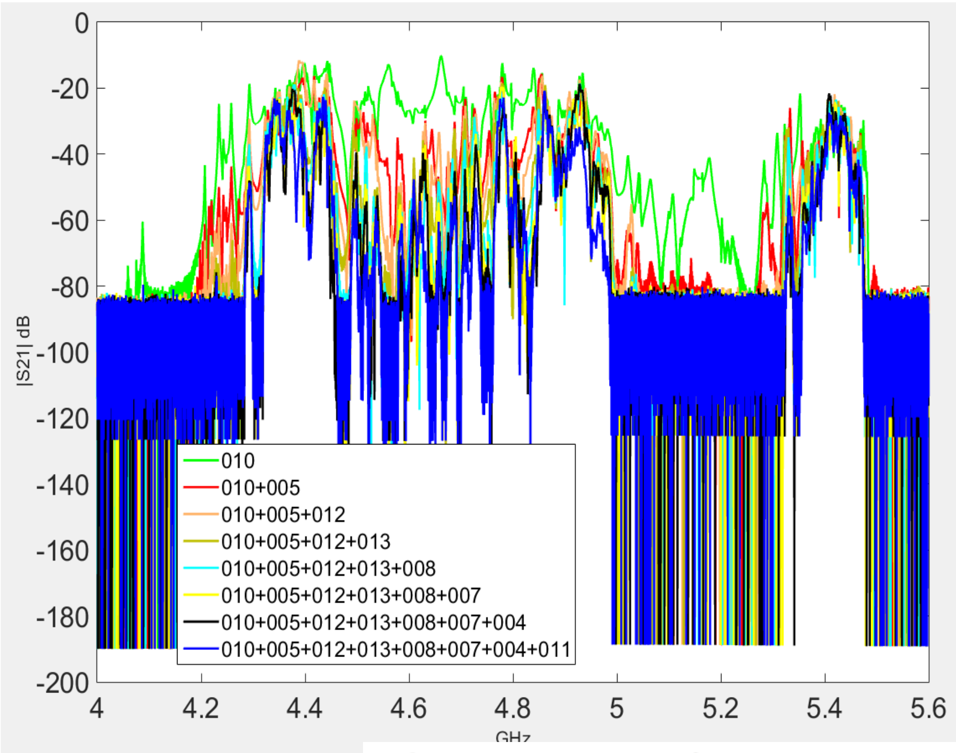




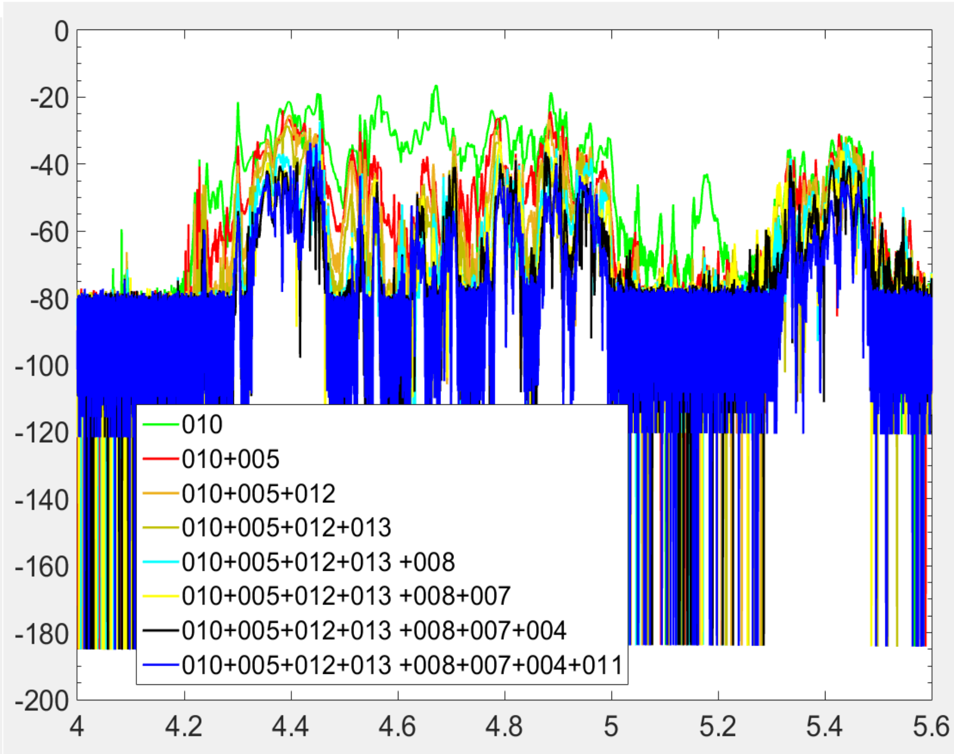
The second dipole band spans ~200 MHz

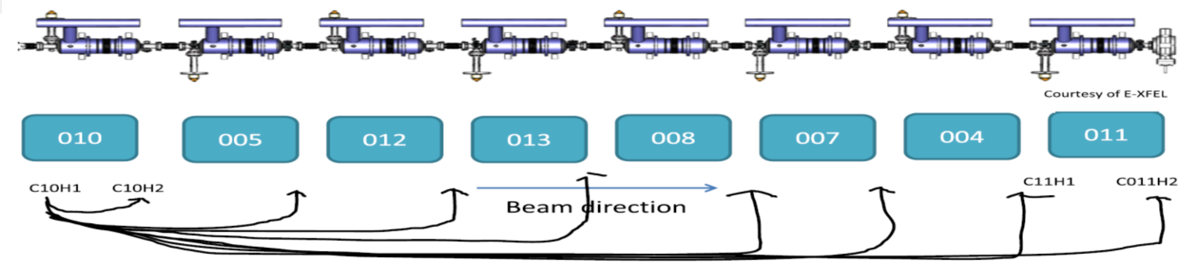
E-XFEL: S21 measurements for coupled cavities

- Warm state (~293K)



- Cold state (~2K)





Summary and Outlook

- For the Beam diagnostics of 1.3 GHz cavities:

    1. For beam position monitor, the drift of calibration is correlated to the phase stability of the system. Beam angle on the beam position prediction is not negligible.---Beam Position Monitor
    2. Circuit model aided the development of beam phase monitor. Signal and noise power level need to be optimized to gain higher resolution.--- Beam Phase Monitor
    3. Beam phase measurements at the E-XFEL is scheduled. Upon the availability of the electronics for the E-XFEL, we will test it during beam time.---Beam position and Phase Monitor

Summary and Outlook

- For the Beam diagnostics of 3.9 GHz cavities:

1. The parameters of the electronics need to be optimized at FLASH.
2. Long term monitoring of the HOM spectra is essential to investigate the instability issue of the HOMBPM at FLASH.
3. HOM spectra measurements ant characterization are done for the E-XFEL.

Thank you for your attention!