HOMBPM study at FLASH

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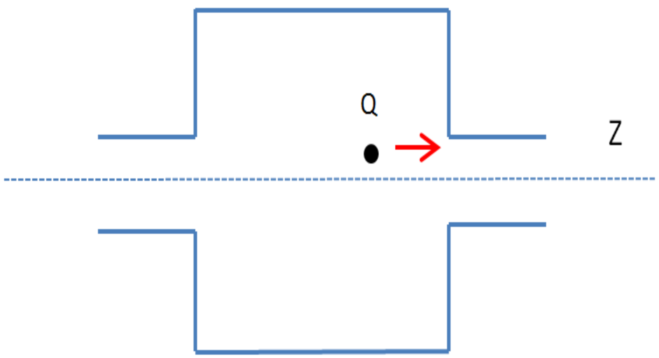
Outline

- Basic principle of an HOMBPM.
- Measurements at FLASH.
  1. HOMBPM measurements for 1.3 GHz cavities
  2. HOMBPM measurements for 3.9 GHz cavities
  3. Investigation of the instability of HOMBPMs.
- Overview of HOM based beam diagnostics.
- Summary and Outlook.

HOM: Higher Order Mode
HOMBPM: HOM based BPM

Wakefield and HOMs

- Wakefield

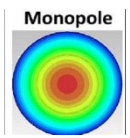


When beam traverses a cavity, it will excite electromagnetic fields inside. The excited fields generally are called wakefield.

- Higher Order Modes

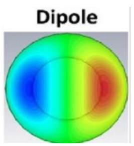
✓ The wakefield can be decomposed into different modes (resonant frequencies). Higher Order Modes or HOMs refer to modes which have higher frequencies than the fundamental mode (1.3 GHz or 3.9 GHz in our case).

✓ Monopole and dipole wake potential can be written as:



$$\boldsymbol{W}_{\parallel}^{\boldsymbol{0}} = \sum_{n=1}^{\infty} \omega_n \left(\frac{R}{Q}\right)_n cos\left(\frac{\omega_n s}{c}\right),$$

$$s > 0$$

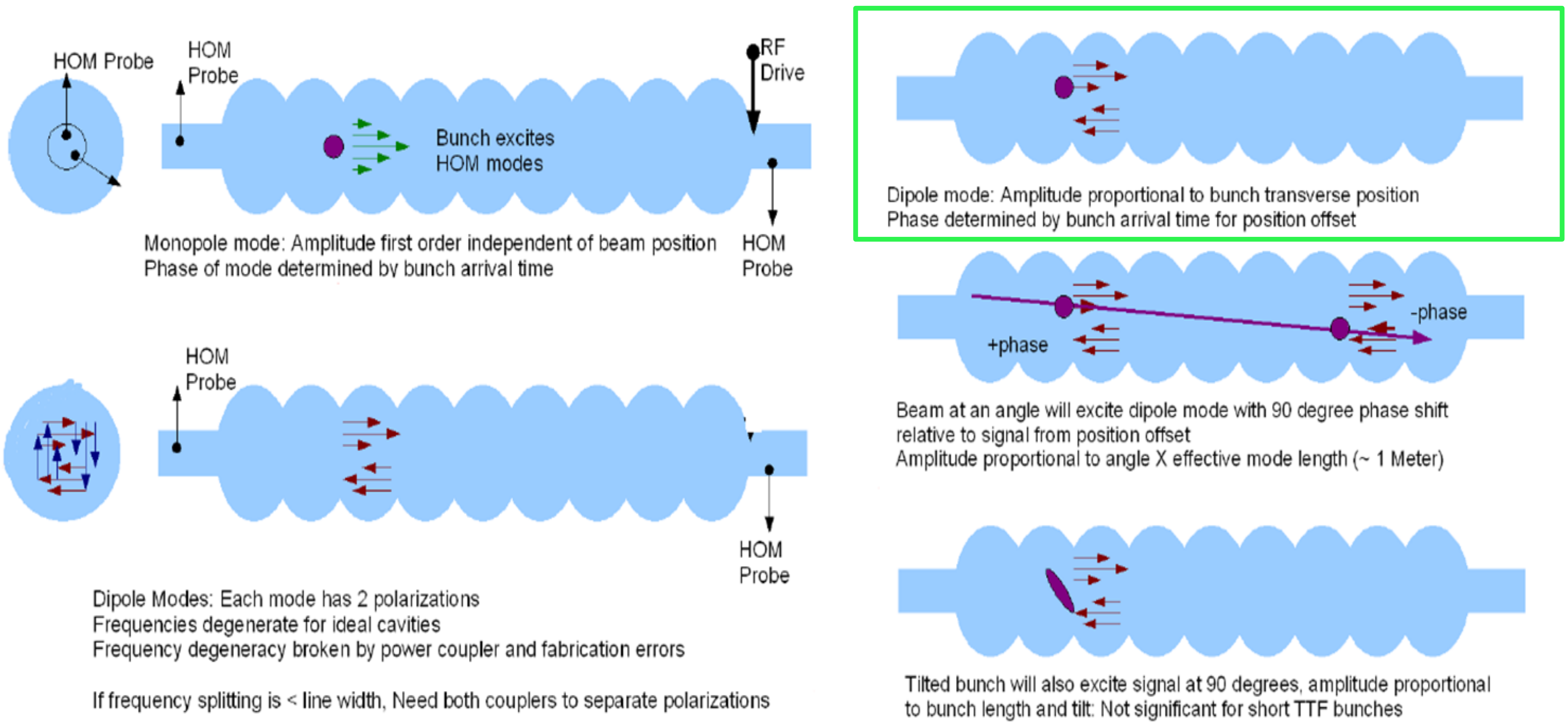


$$\boldsymbol{W}_{\perp}^{\boldsymbol{1}} = (\boldsymbol{x} + \boldsymbol{y})c \sum_{n=1}^{\infty} \left(\frac{R}{Q}\right)_n sin\left(\frac{\omega_n s}{c}\right),$$

$$s > 0$$

R. Wanzenberg, TESLA 2001-33, 2001

HOM response to beam



R. M. Jones, Workshop on HOM Damping in SCRF Cavities, 13thOct 2010

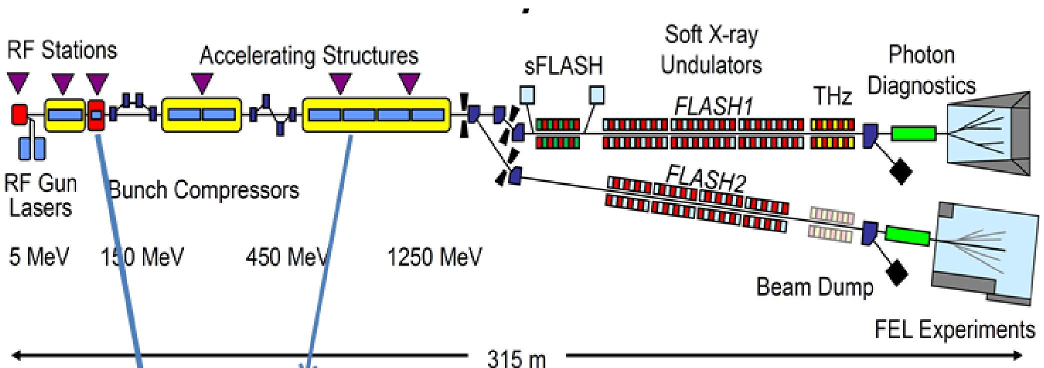
Principle of an HOMBPM

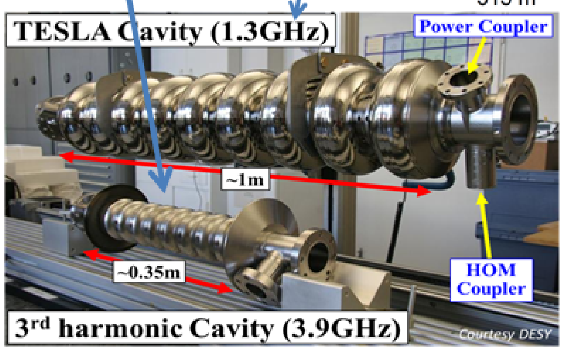
- Measured dipole voltage ∝ $q \cdot (x + y) \cdot \frac{R}{Q}$
- To get beam position:
  - ✓ Normalize with charge q
  - ✓ Select the dipole mode with higher R/Q
- The basic principle is the same for both 1.3 and

3.9 GHz cavities. The wakefield is much stronger in 3rd harmonic cavities:

$$\boldsymbol{W}_{\parallel} \propto \omega^2 \text{ and } \boldsymbol{W}_{\perp} \propto \omega^3$$

HOMBPMs at FLASH



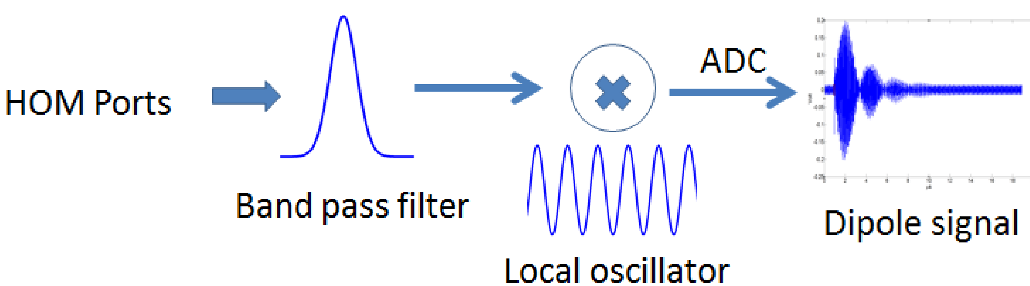


- Each cavity has 2 HOM couplers
- The signal is brought out by long cables.
- Signal is filtered, down mixed and sampled at 108 MHz

- 10 channels for HOMBPM for 3rd Harmonic cavity

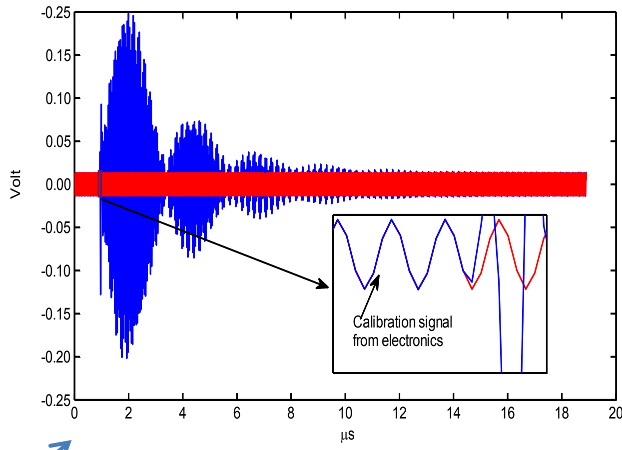
- ACC1-ACC5 modules are equipped with HOMBPM for 1.3GHz cavities.

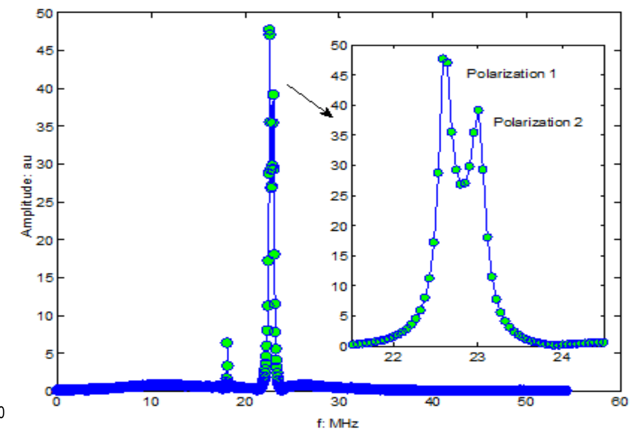
- All HOM raw data are accessible from DOOCS

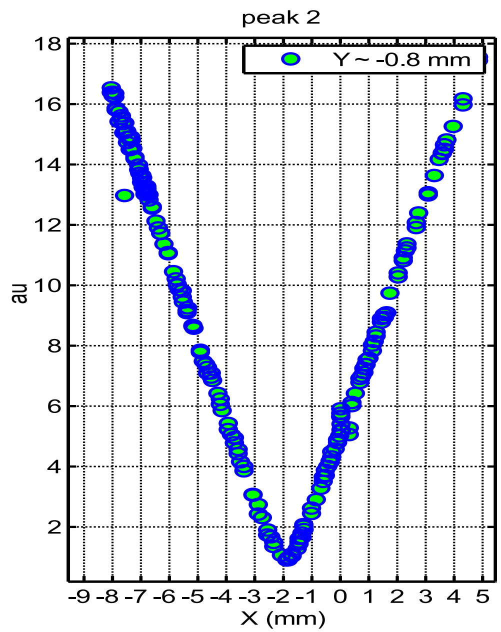


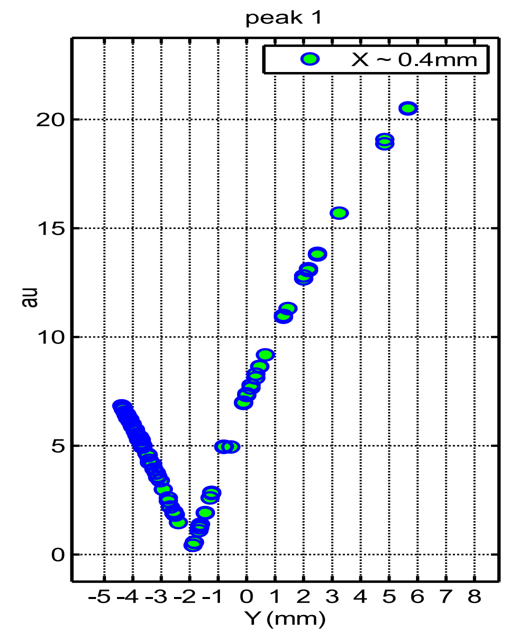
HOMBPM for 1.3GHz cavities

Mode	*f* (GHz)	*R/Q* (Ω/cm²)
EE-1	1.6291	0.0014
EE-2	1.6369	0.0636
EE-3	1.6497	0.0014
EE-4	1.6671	0.3767
EE-5	1.6885	0.0689
EE-6	1.7129	5.5392
EE-7	1.7392	7.7817
EE-8	1.7656	1.0453
EE-9	1.7912	0.8059
EE-10	1.8005	0.3536





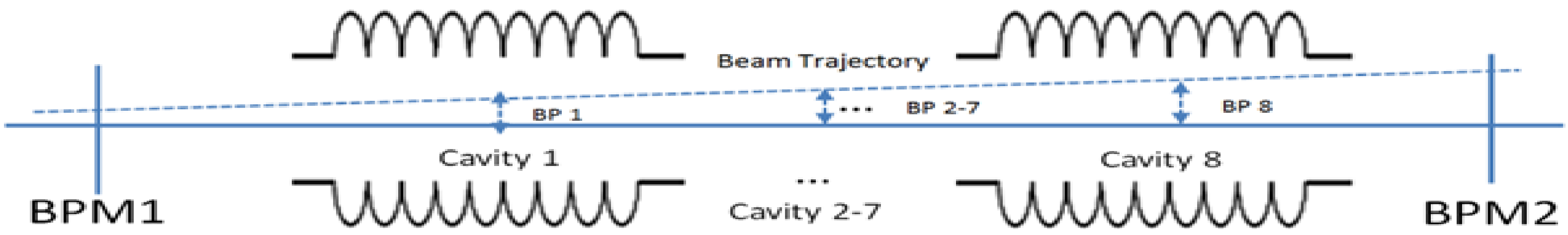




R. Wanzenberg, TESLA 2001-33, 2001

Calibration of an HOMBPM

- Calibration of an HOMBPM



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.

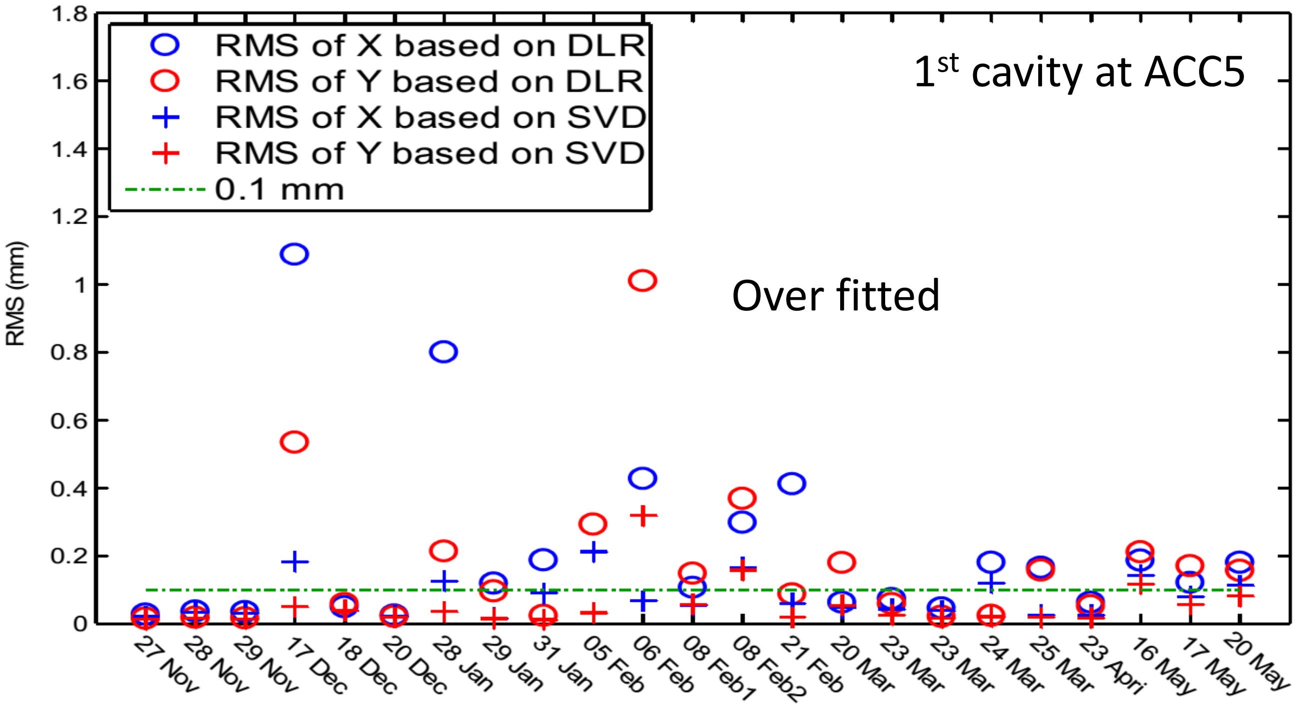
$$\begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} \\ \vdots & \vdots \\ C_{n1} & C_{n2} \end{bmatrix} = \begin{bmatrix} X_{11} & Y_{11} \\ \vdots & \vdots \\ X_{m1} & Y_{m1} \end{bmatrix}$$

DLR: Direct Linear Regression
SVD: Singular Value Decomposition

HOMBPM for 1.3GHz cavities

- Dipole datasets are from parasitic measurements and dedicated beam time.
  - ✓ For parasitic datasets, machine status is unknown to some extent. Pseudo calibration has been performed.
  - ✓ For beam time dataset, we performed dedicated calibration.

Calibration results for 1.3GHz cavity



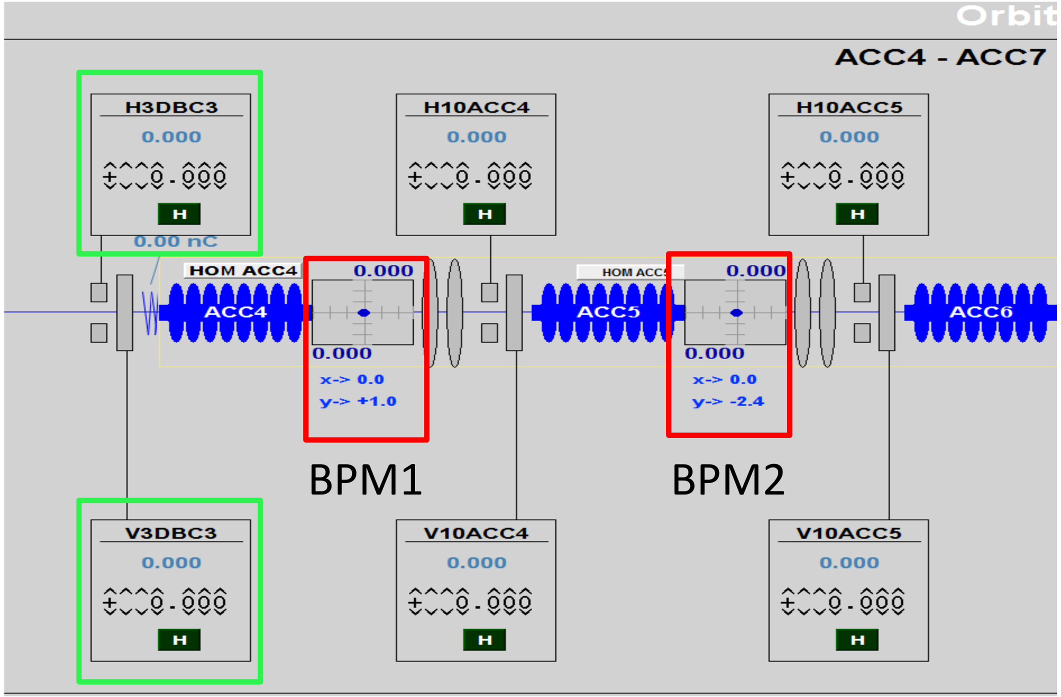
Resolution is evaluated on each day instead of being evaluated over time based on one calibration.

DLR data from 17 Dec, 28 Jan, 06 Feb can be excluded.

Based on these parasitical datasets, it is clear that some cannot give beam position properly in terms of resolution.

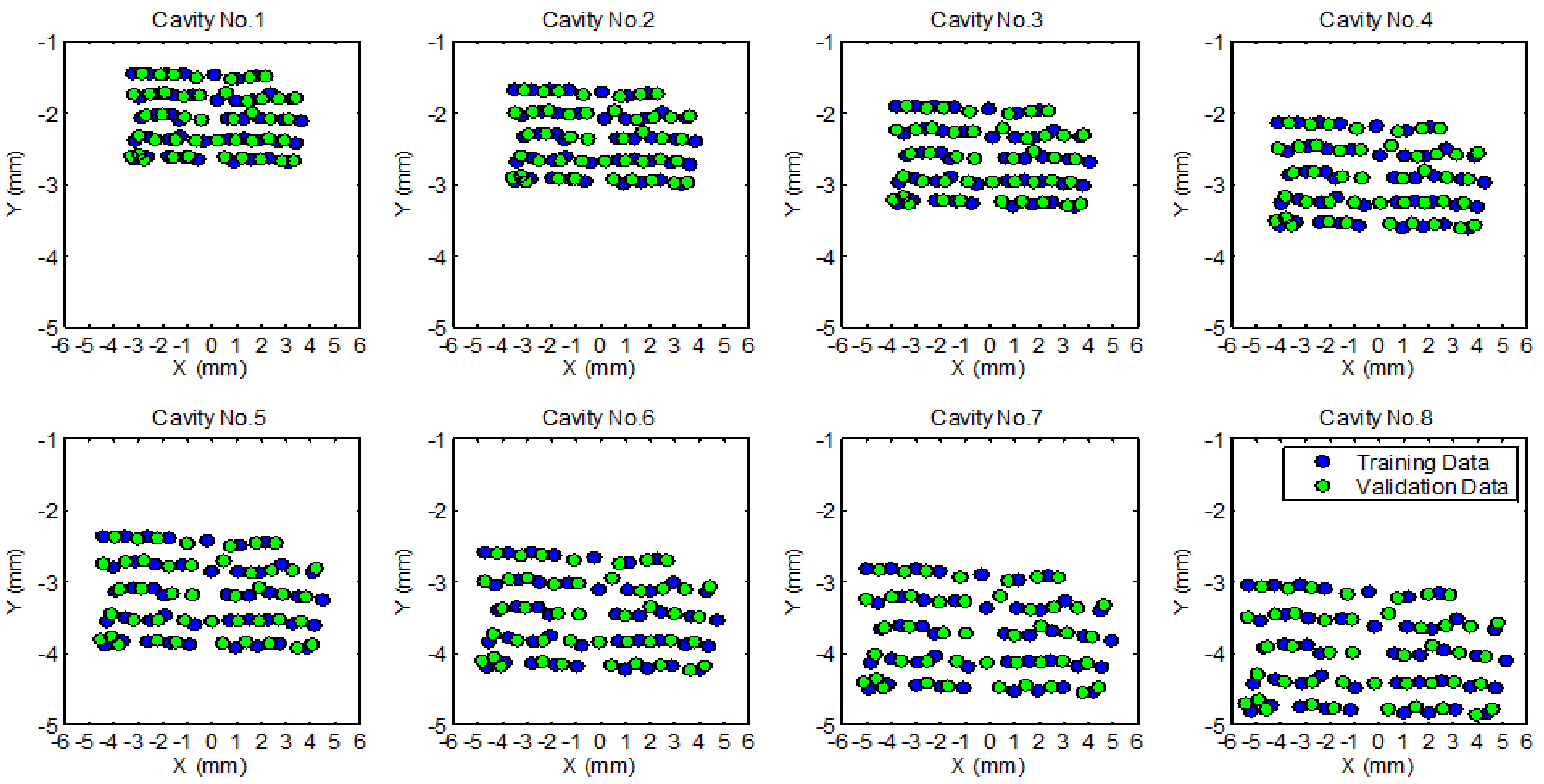
Calibration during beam time

- HOMBPM calibration based on beam time



Magnets between two cavity BPMs were turned off;
We move the beam by using H3DBC3 and V3DBC3.

Beam position patterns along module

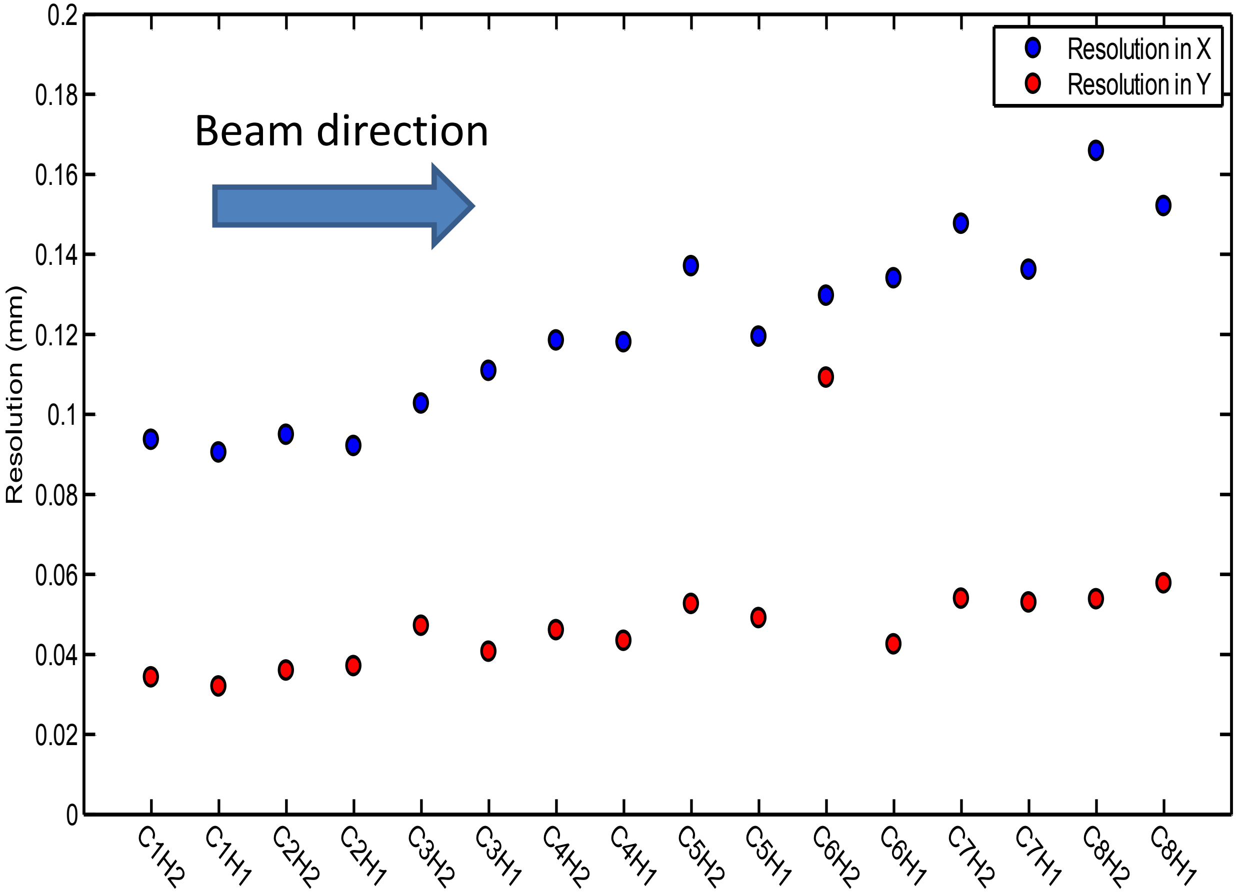


Training data: used to calibrate the HOMBPM.

Validating data: used to evaluate the HOMBPM

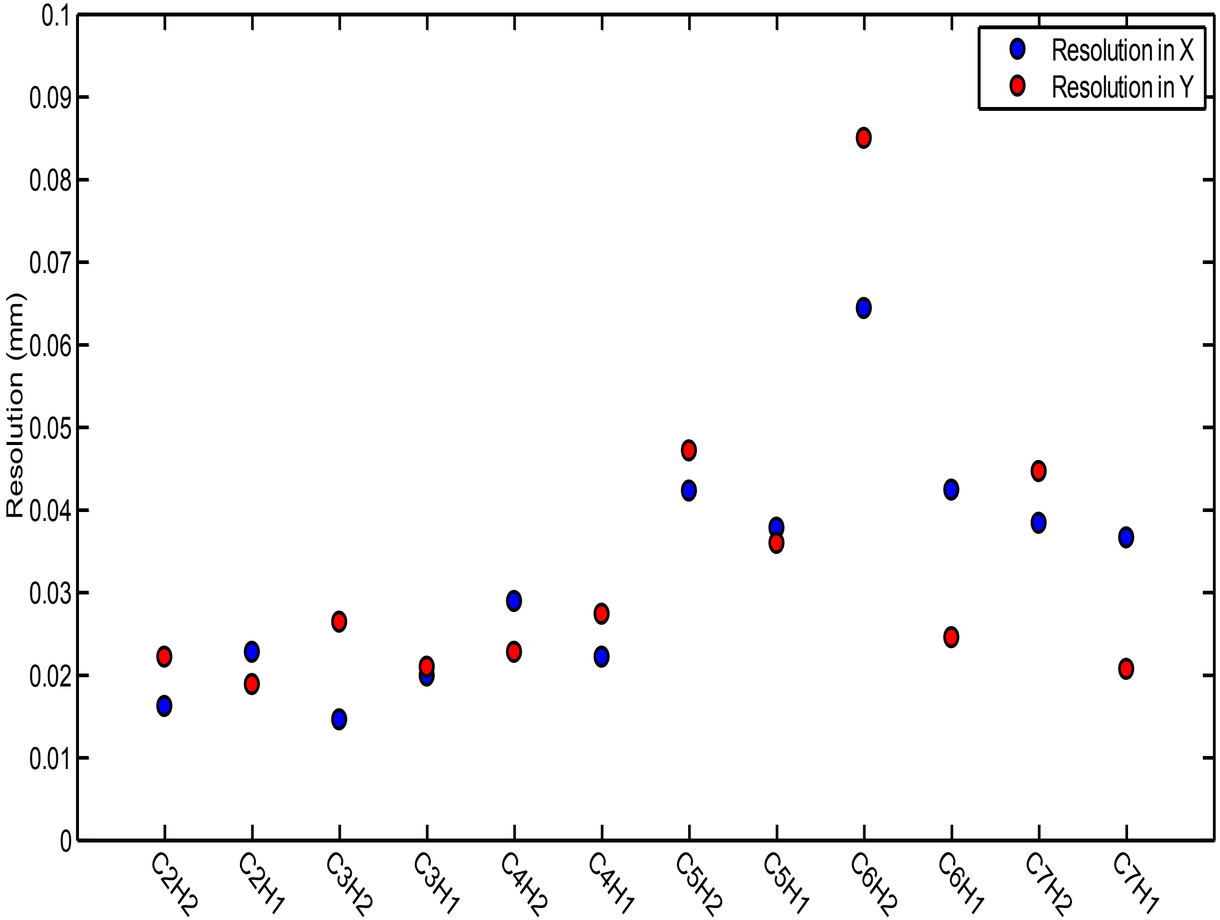
Incomplete scan due to limited beam time

1st method to evaluate HOMBPM



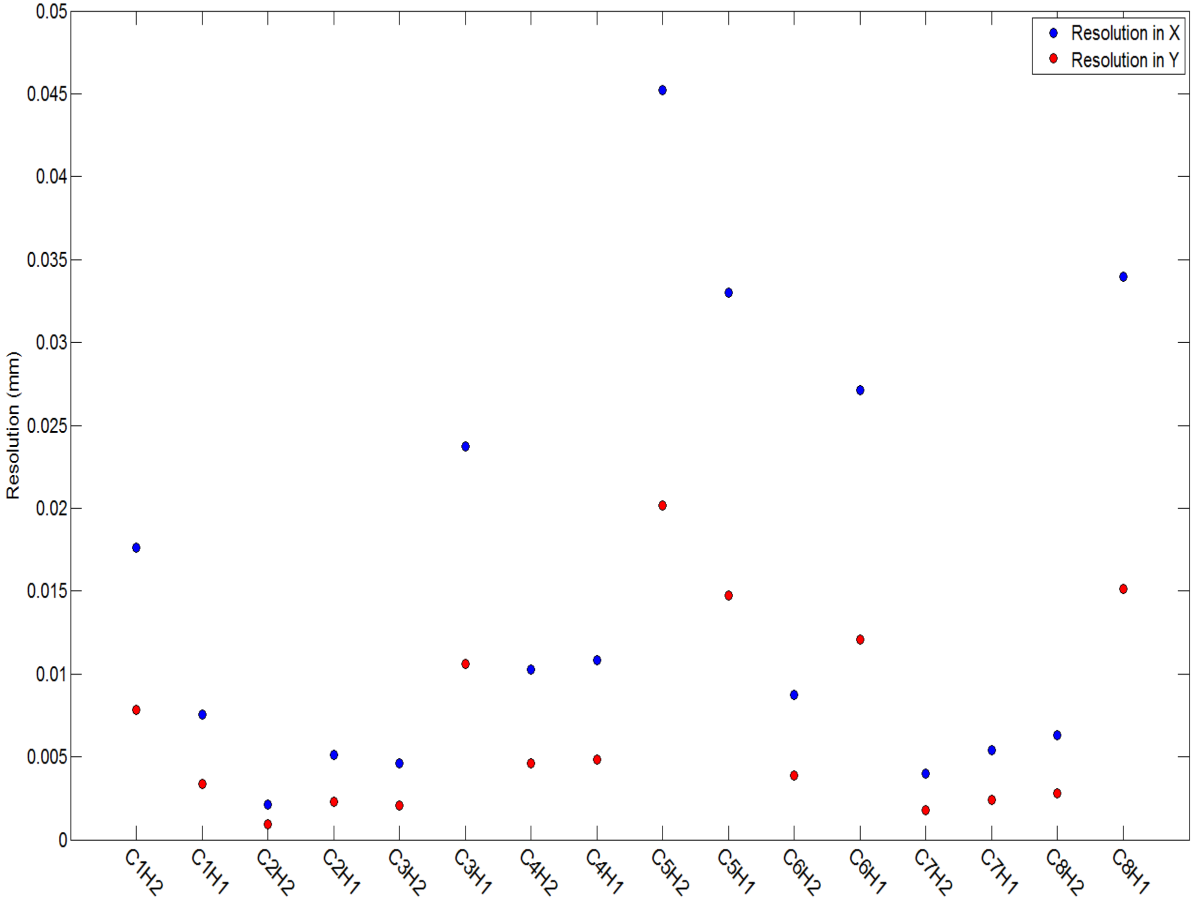
- Resolution based on rms of HOMBPM readout and BPM readout.
- Resolution study at ACC5
- X is worse than Y.

2nd method to evaluate HOMBPM



- Resolution based on rms of HOMBPM readout and neighbor HOMBPMs readout.
- Resolution study at ACC5
- Intention is to minimize influence from BPMs used for calibration.

3rd method to evaluate HOMBPM

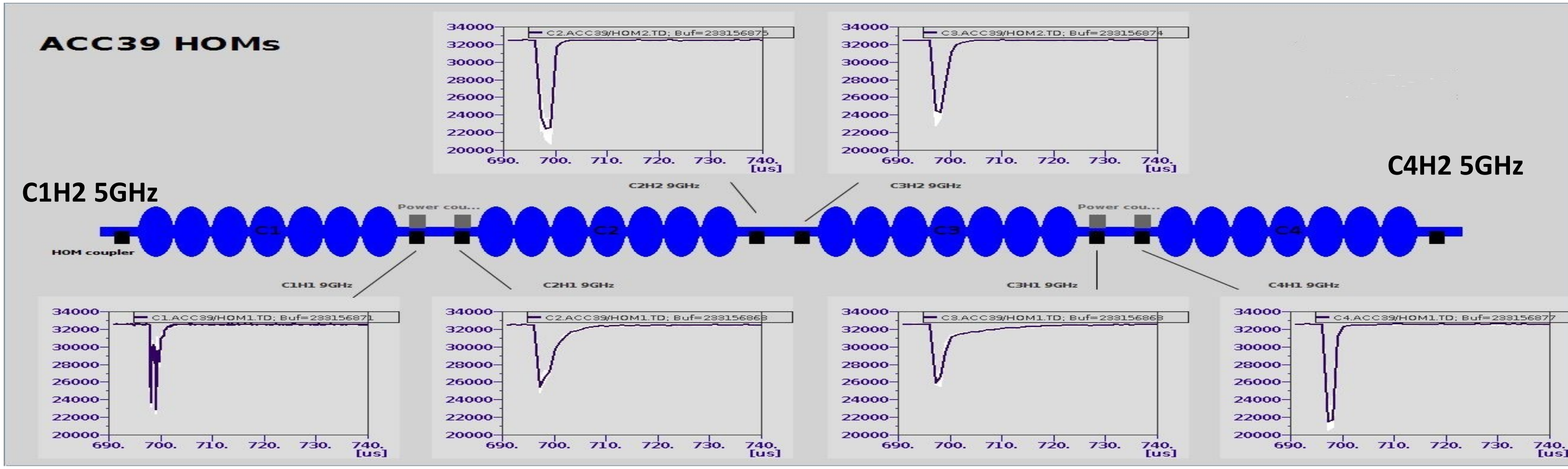


- Resolution based on rms of 16 channels of HOMBPM readout
- Resolution study at ACC5

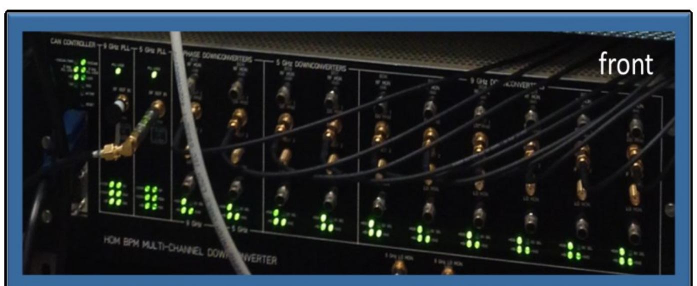
Summary of HOMBPM of 1.3GHz cavity

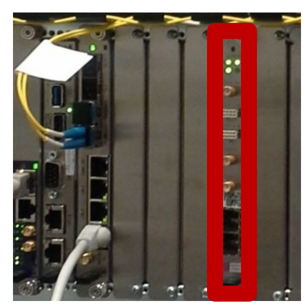
- We could calibrate the HOMBPM to tens of microns resolution. However, the current task is to understand the instability over time.
- The resolution of the HPMBPMs is essentially the resolution of HOMBPMs plus BPMs used for calibration.
- In any case, we can still use these HOMBPMs for aligning the beam.

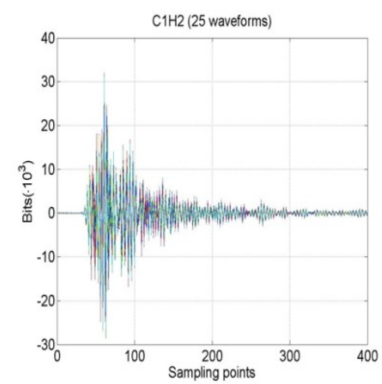
HOMBPMs for 3.9 GHz cavities



Band pass Filter ~5.43 GHz or 9.06 GHz 100 MHz BW → Mixer → 30 MHz IF → µTCA Digitizer SIS8300 (108MS/sec)



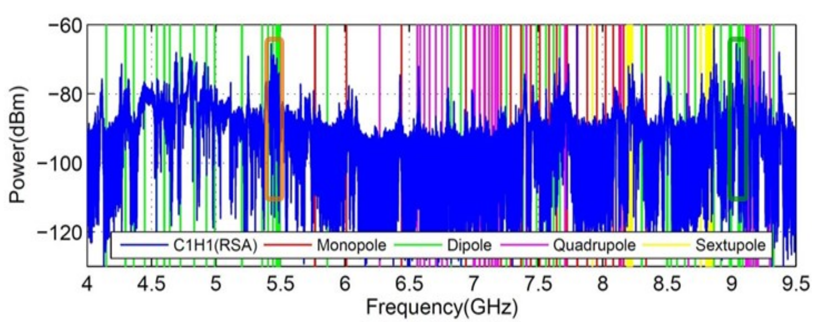




N. Baboi et al, TUPF06, IBIC14

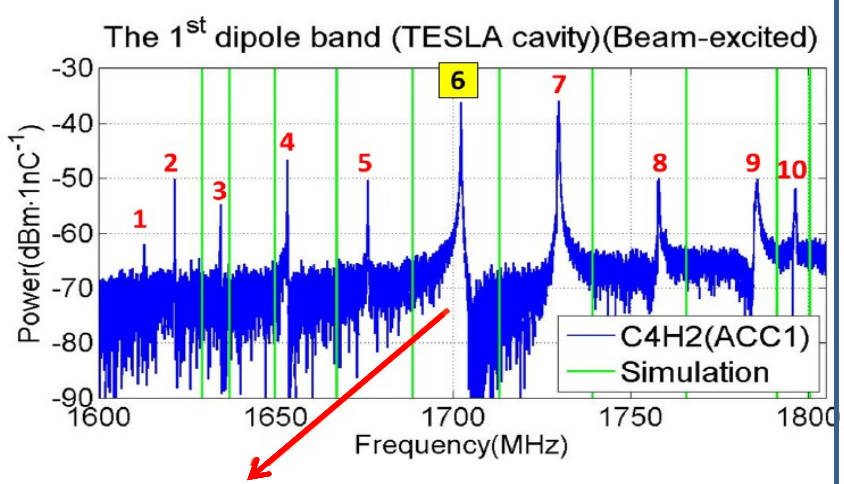
Spectrum comparison between 3.9 and 1.3 GHz cavities

Mode type	Freq./BW (MHz)	Advantages	Disadvantages
1st & 2nd band	5465 / 30	High R/Q	Not localized
5th band	9058 / 30	Localized Cavity-based	Low R/Q



It is difficult to identify single dipole mode, a band of dipoles are used for beam position monitor.

Mode type	Freq./BW(MHz)	Advantages
TE111-6	1721/20	High R/Q; Localized

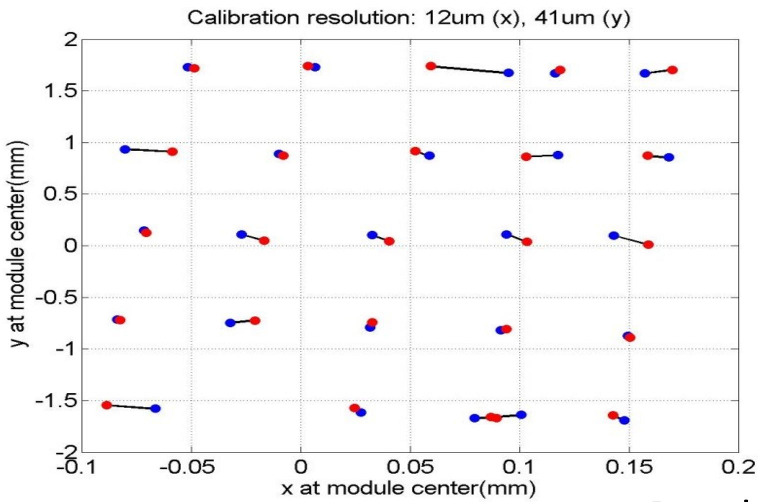


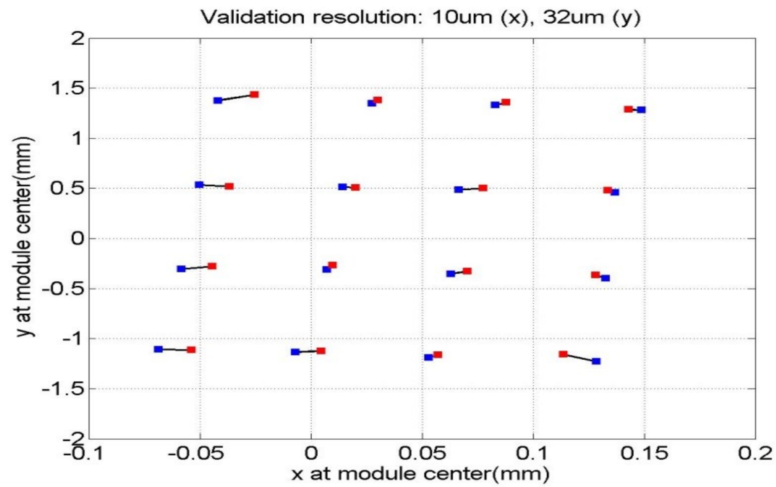
Dipole used for HOMBPM

Spectrum for 3.9 GHz cavity

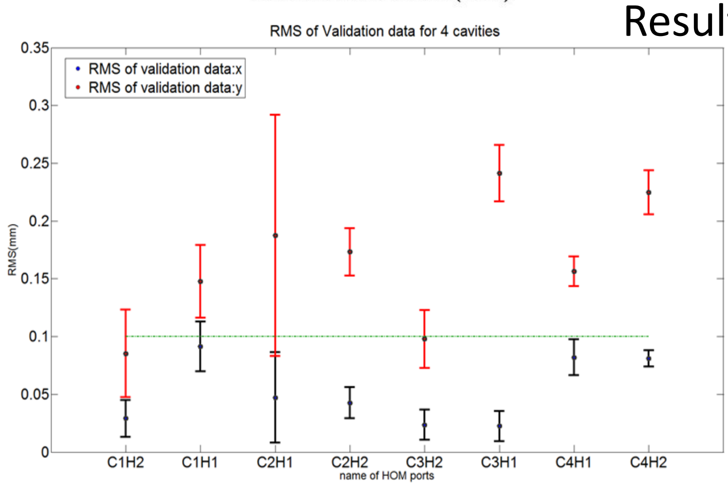
Spectrum for 1.3 GHz cavity

HOMBPM for 3.9 GHz cavities





Result from August 2014



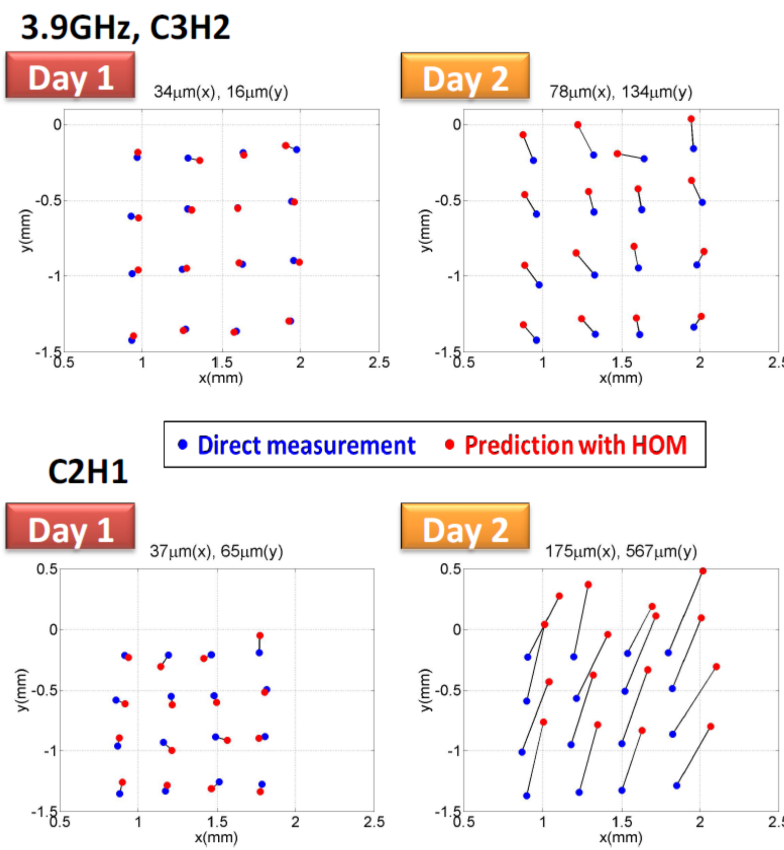
Result from May 2014

- In general good results for 5 GHz channels and 9 GHz/x
- High RMS error for 9GHz/y: Possibly instability of signals in electronics

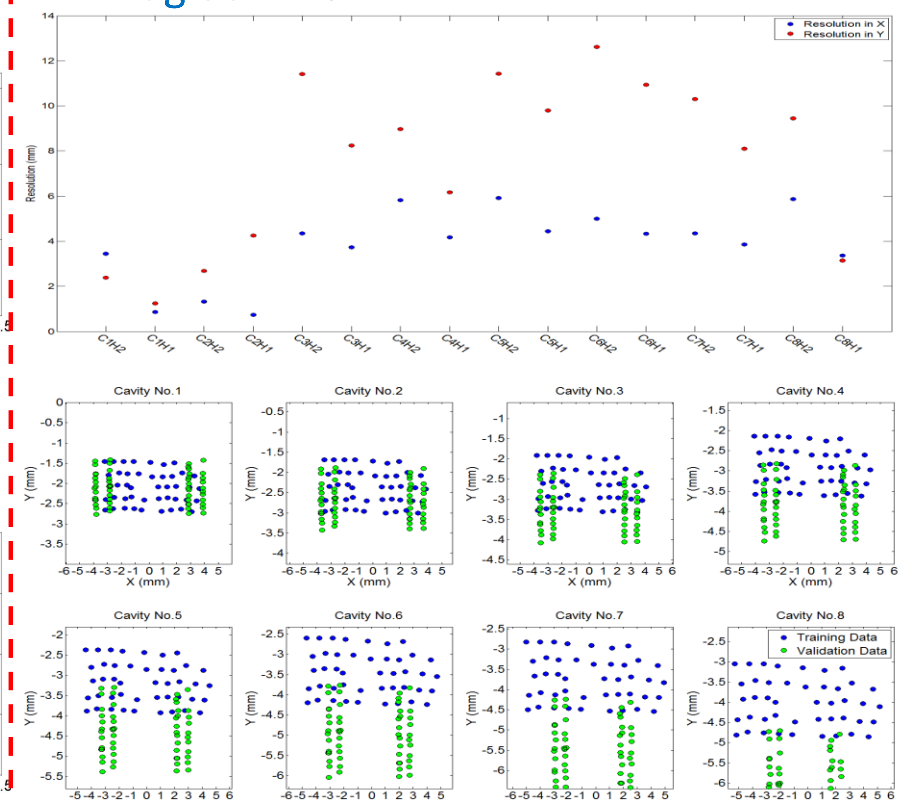
Issues for HOMBPMs (1.3 and 3.9GHz)

- Instability of HOMBPM: the resolution will drift over time after one dedicated calibration.

HOMBPM for 3.9 GHz

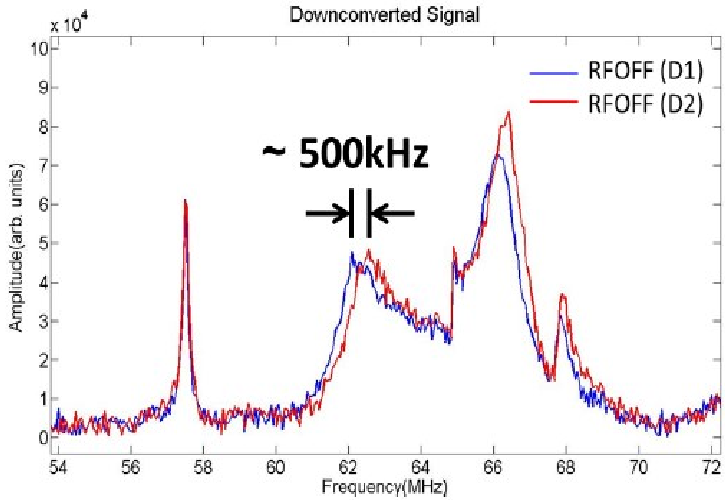


Validation on Feb 8th 2014 at ACC5 calibrated in Aug 30th 2014



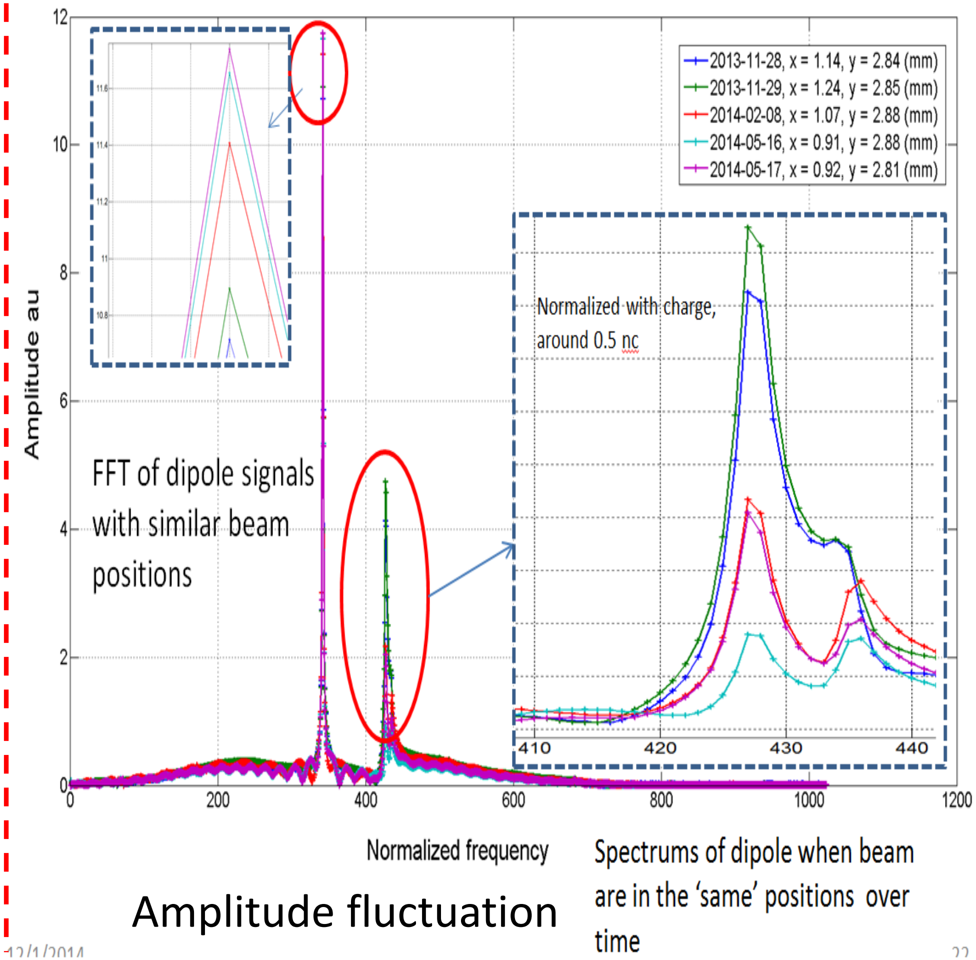
Feb 8th Aug 30th

Issues for HOMBPM (1.3 and 3.9GHz)



for 3.9GHz cavity

Frequency drift will modulate the waveform in time domain



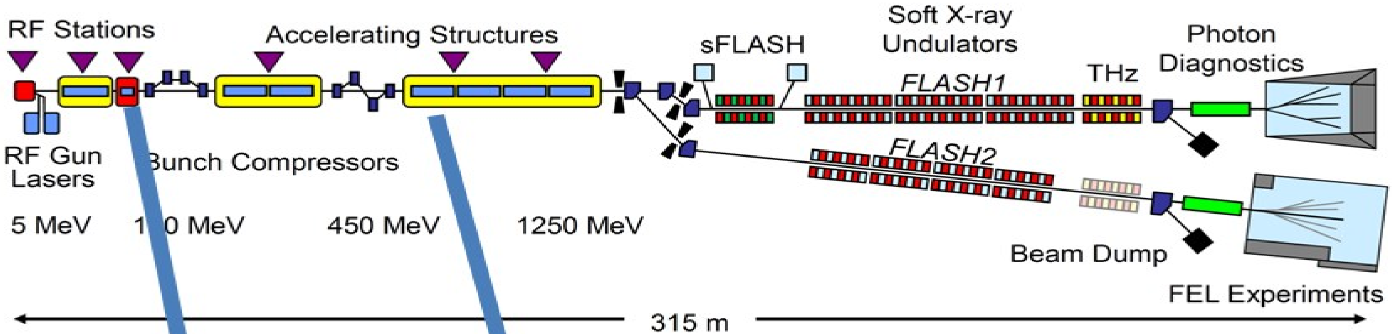
Amplitude fluctuation

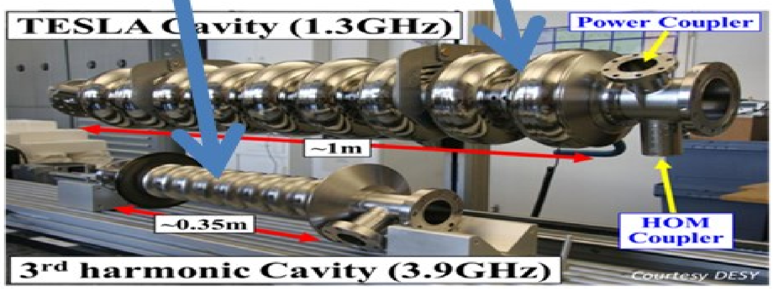
FFT of dipole waveforms from 1.3GHz cavity

The suspect list

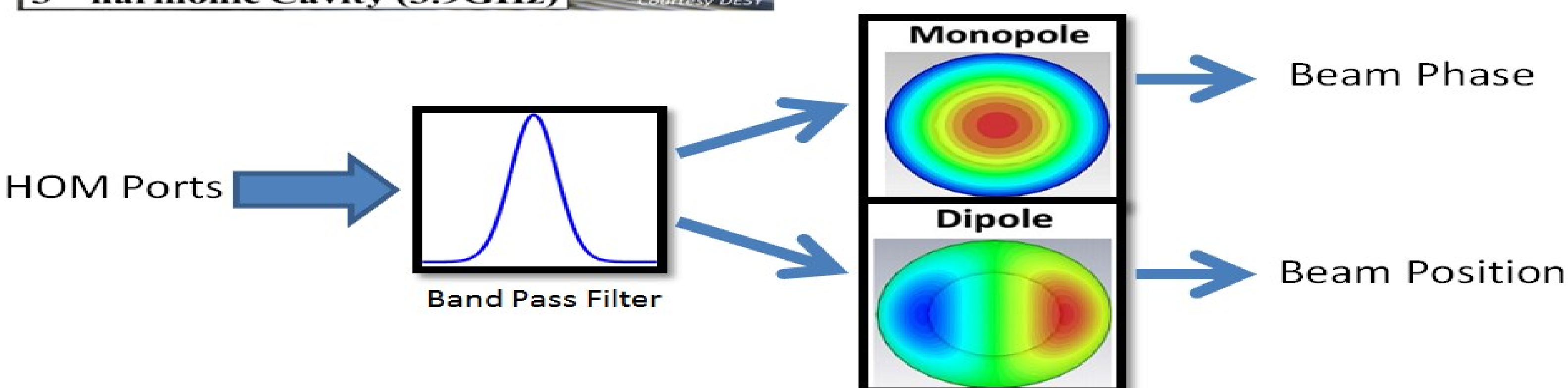
- The stability of the signal:
  - ✓Frequency drift (Observed in 3.9, unclear in 1.3)
  - ✓Phase jitter or drift
  - ✓Stability of the electronics
- Calibration and characterization means.
  - ✓ Time domain or frequency domain?
  - ✓ The indication of systematic drift.

Overview of HOM based Beam Diagnostics





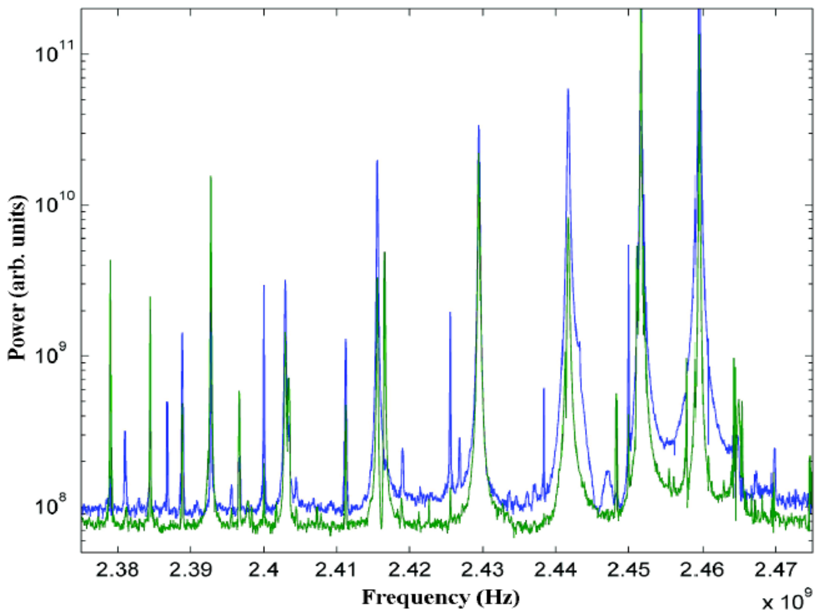
Signals from HOM ports are used for beam diagnostic purpose.

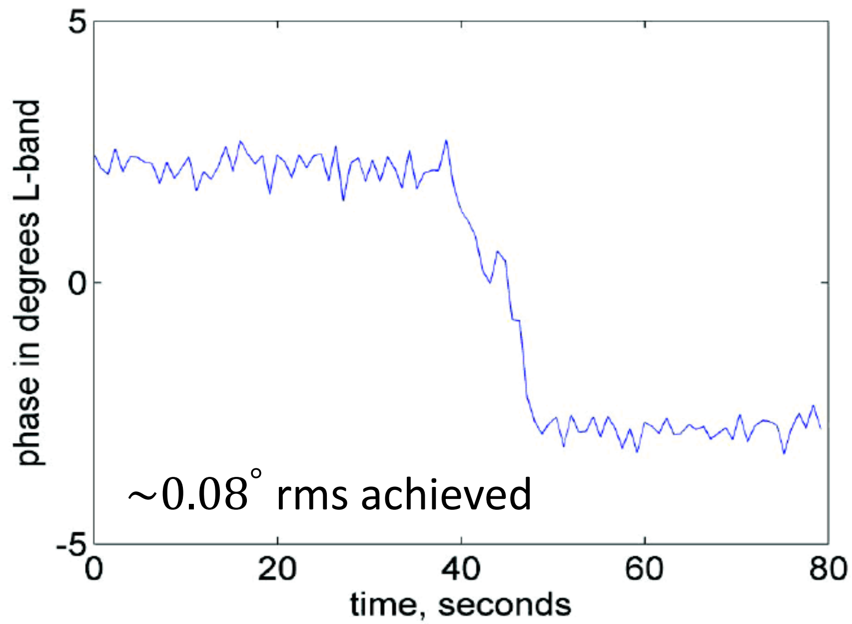


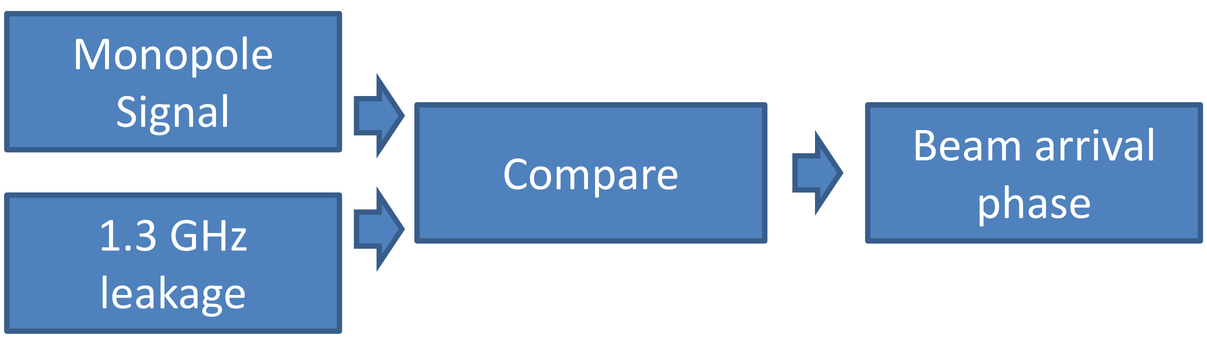
In addition, both modes can deliver beam charge information

HOM based Beam Phase measurement

2nd monopole band from TESLA cavity







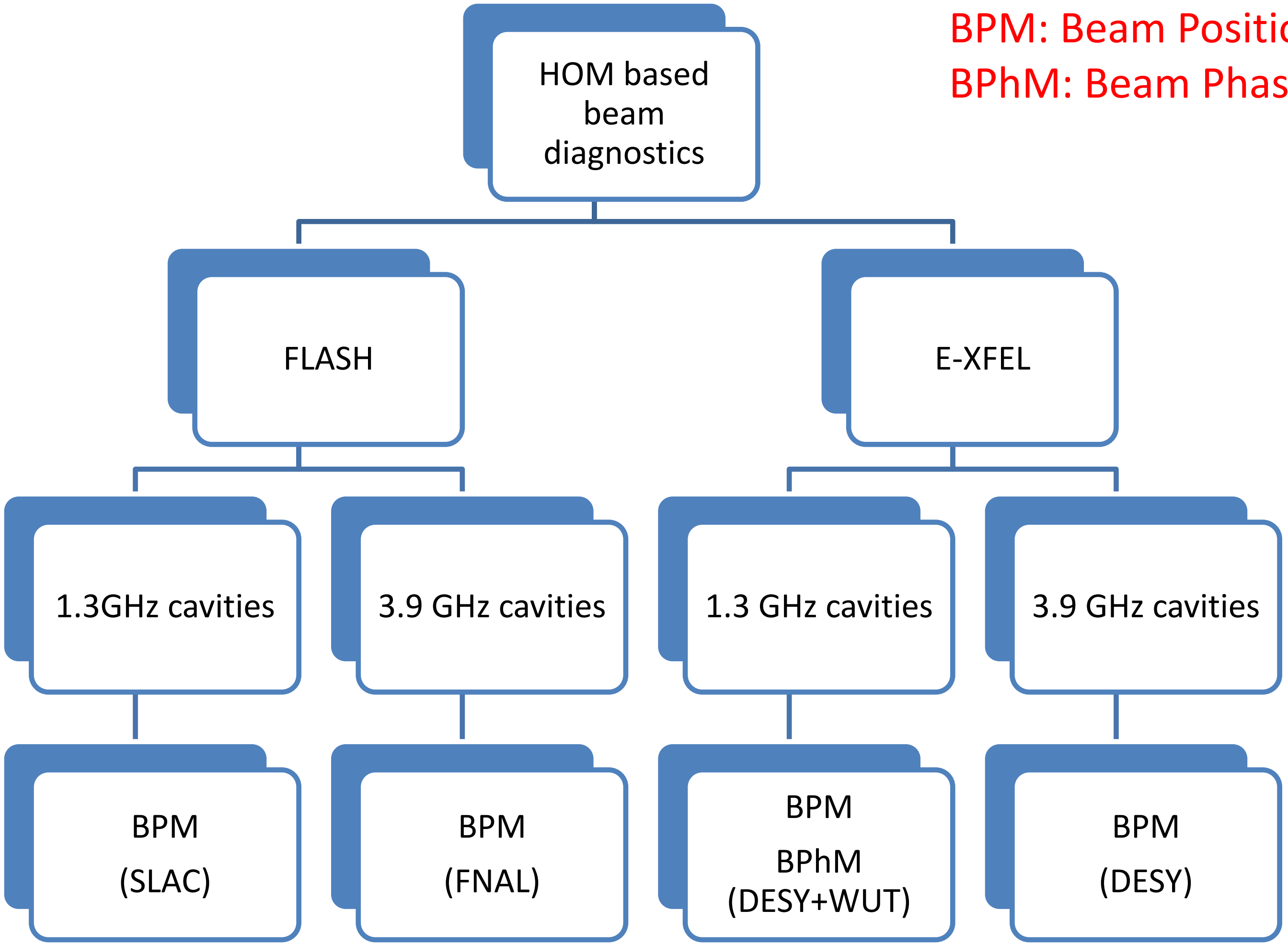
Advantages:

- Both signal are from the same cable.
- Monopole is always available

S. Molloy et al., Phys. Rev. ST-AB 9, 112802 (2006)

HOM based Beam Diagnostics – FLASH and E-XFEL

BPM: Beam Position Monitor
BPhM: Beam Phase monitor



Summary and Outlook

- HOMBPMs can be calibrated to tens of microns resolution. Frequency drift was observed in 3rd harmonic cavity. Dipole spectrum fluctuation was observed in 1.3 GHz cavity.
- Instability study is still going on. We plan to monitor beam induced dipole spectrum over time at FLASH.
- We plan to build a circuit model for both 1.3 and 3.9 GHz cavity to study effects of various perturbations.
- Next beam time (January 2015), we plan to calibrate the HOMBPMs (1.3 and 3.9 GHz) completely.
- Beam phase measurement will start soon. It is scheduled for the beam time as well.

Thank you for your attention!