FLASH.
Free-Electron Laser FLASH

European XFEL

HOM-based Diagnostics in SC Accelerating Cavities at FLASH and the European XFEL

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MDI group
for the HOM-team

DESY-TEMF Meeting
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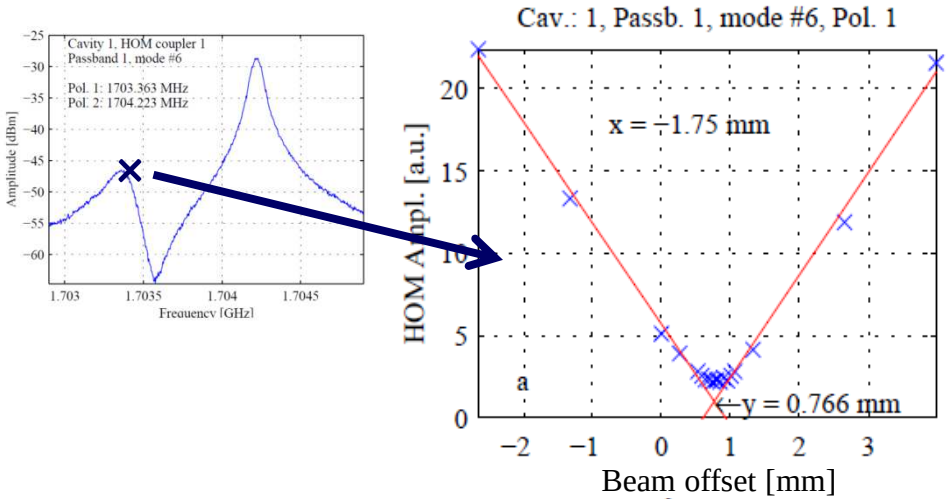
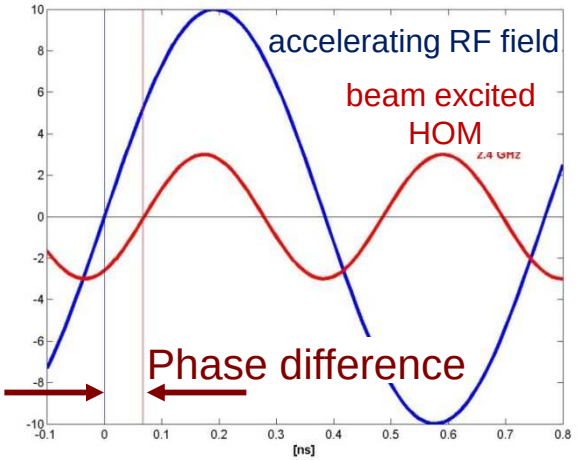
HELMHOLTZ GEMEINSCHAFT

DESY

Beam Diagnostics with HOMs

- HOMs carry information about the beam properties
  ⇒ they can be used to monitor the beam
  - The strength of the excited dipole modes depends linearly on the beam charge and transverse position: $q \cdot r \cdot (R/Q)$
  - The timing of excited modes depend on beam arrival time (beam phase)





Benefits of HOM-based Diagnostics

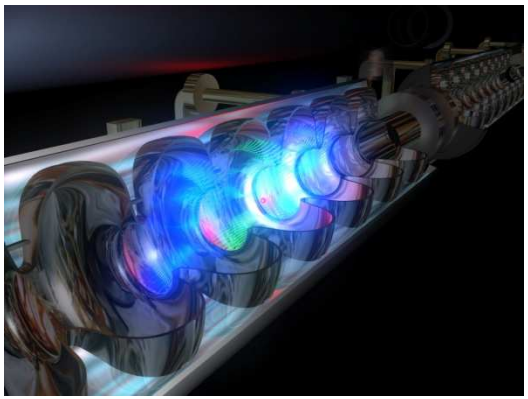
- Align the beam based on the signals which can damage beam quality, therefore reduce the (long-range) wakes
- Measure the transverse beam position
- Measure the transverse cavity alignment in the cryo-module

- Direct, on-line measurement of beam phase wrt RF phase

- Does not require additional vacuum component, therefore relatively cheap

Outline

- HOM-based Beam Position Monitoring (HOM-BPM)
  - HOM-BPMs in 1.3GHz cavities
  - HOM-BPMs in 3.9GHz cavities
    coupled cavities
  - Stability study



- HOM-based beam phase monitoring (HOM-BPhM)

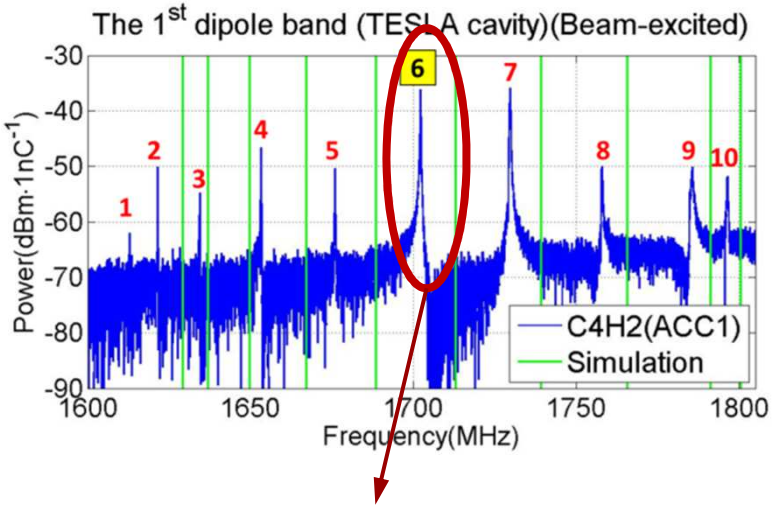
- Summary and Outlook

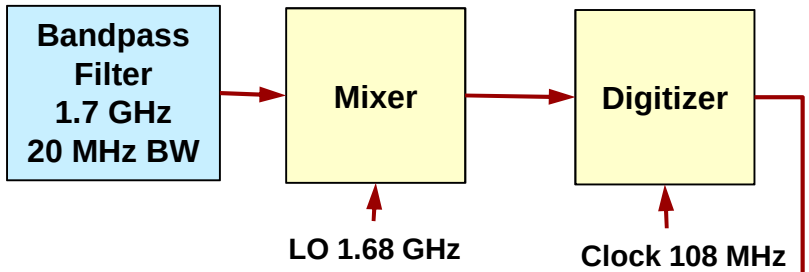
1.3 GHz Cavities

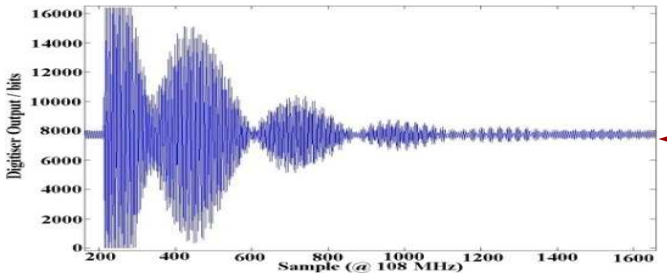
- HOMBPM-electronics installed in FLASH
  - Use 1 dipole mode at 1.7 GHz, which has higher R/Q
  - Used as operator tool for beam alignment
  - Used for measurement of cavity alignment

- Installed in 5 cryo-modules in FLASH

Joe Frisch, SLAC

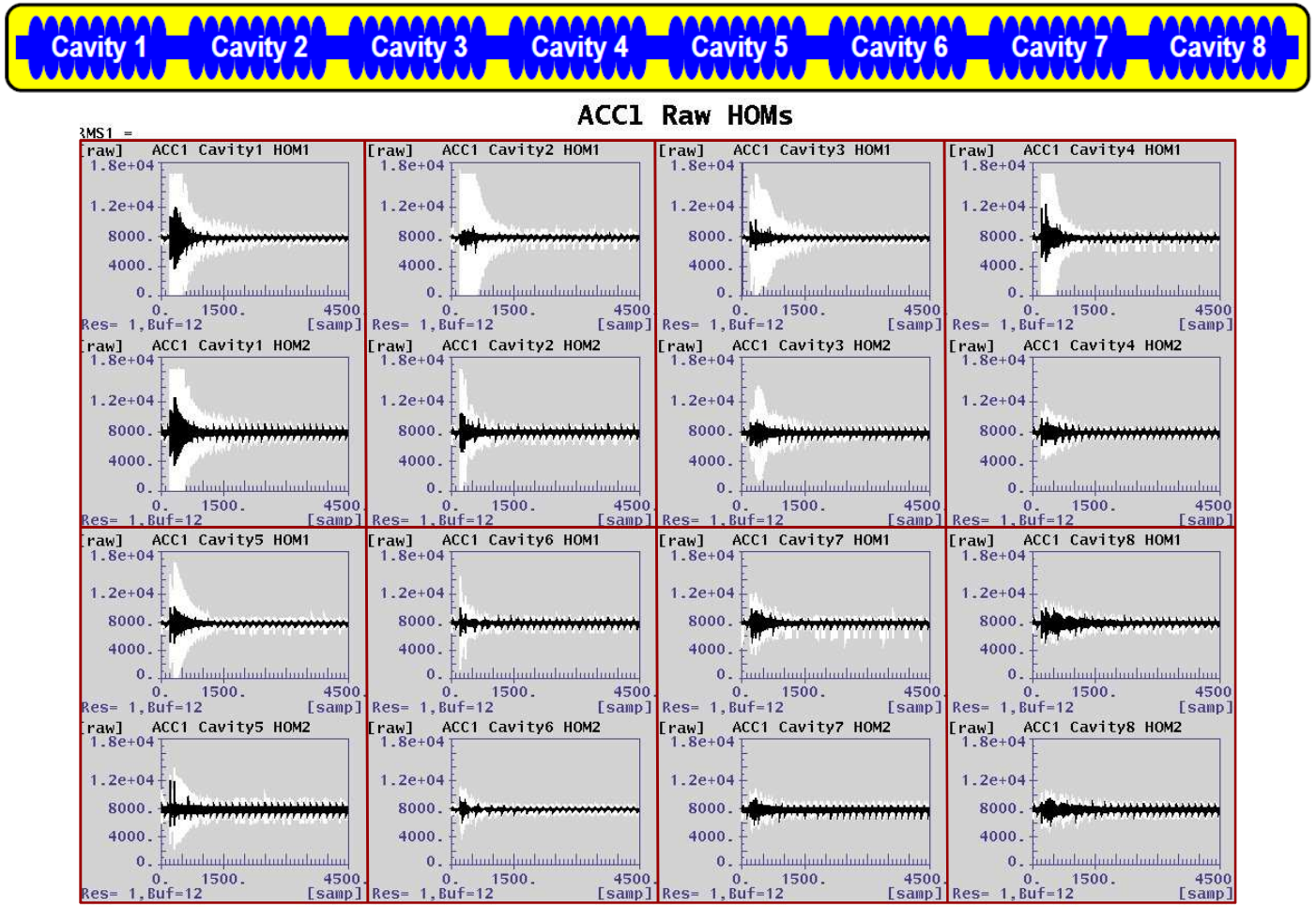




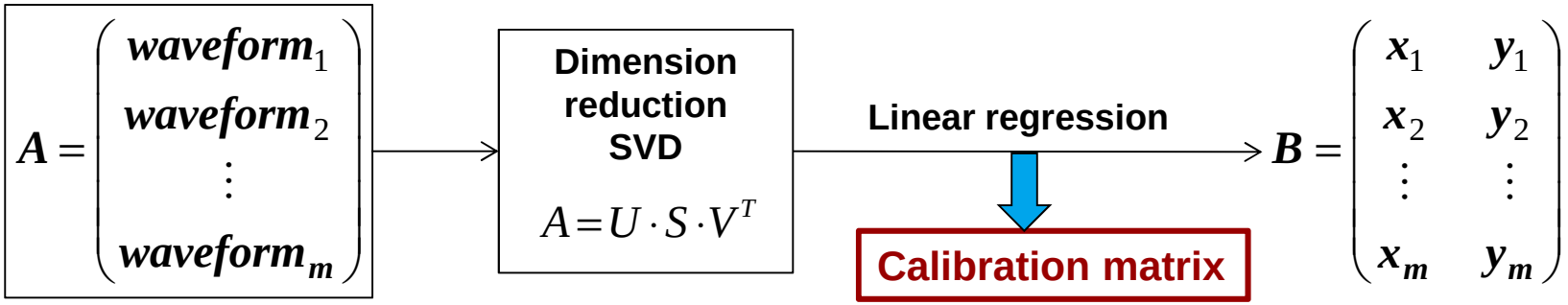


1.3 GHz Cavities: Beam alignment

> Used for beam alignment, mainly during commissioning

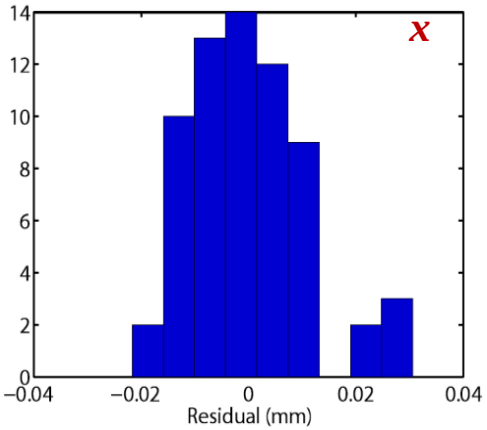


1.3 GHz Cavities: HOM-BPM Calibration



- Calibration more complicated than in standard cavity BPMs
  - Split modes
  - Polarization direction is usually not horizontal or vertical, and, generally unknown
  - Different frequency in each cavity (1.7 GHz ± 10 MHz)
- Demonstrated use as BPM
  - 10 μm rms resolution

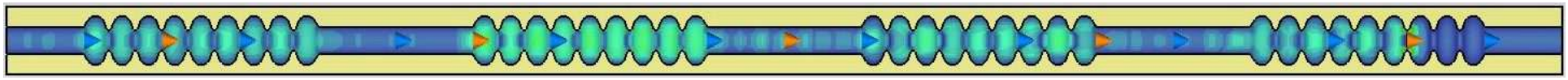
Resolution: 9μm



Stephen Molloy, SLAC (now ESS)

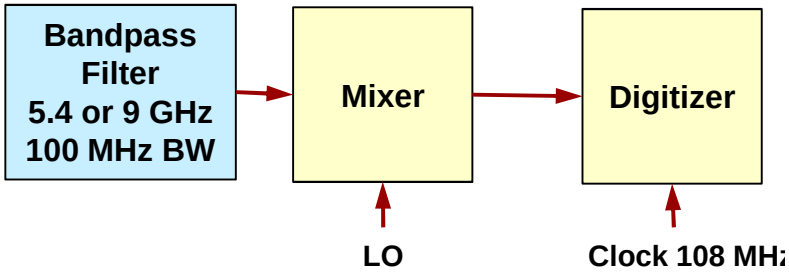
3.9 GHz Cavities

- Important to monitor and reduce HOMs due to higher impact on the beam
  - Higher frequency
  - Smaller iris apertures
  - Low beam energy
- No trivial copy of system for 1.3 GHz cavities, due to:
  - Coupling of the cavities (4 at FLASH, 8 at the E-XFEL)
    Beam pipe cut-off: 4.39GHz
  - Not possible to separate one dipole mode
  - Propagating modes make local beam position measurement difficult

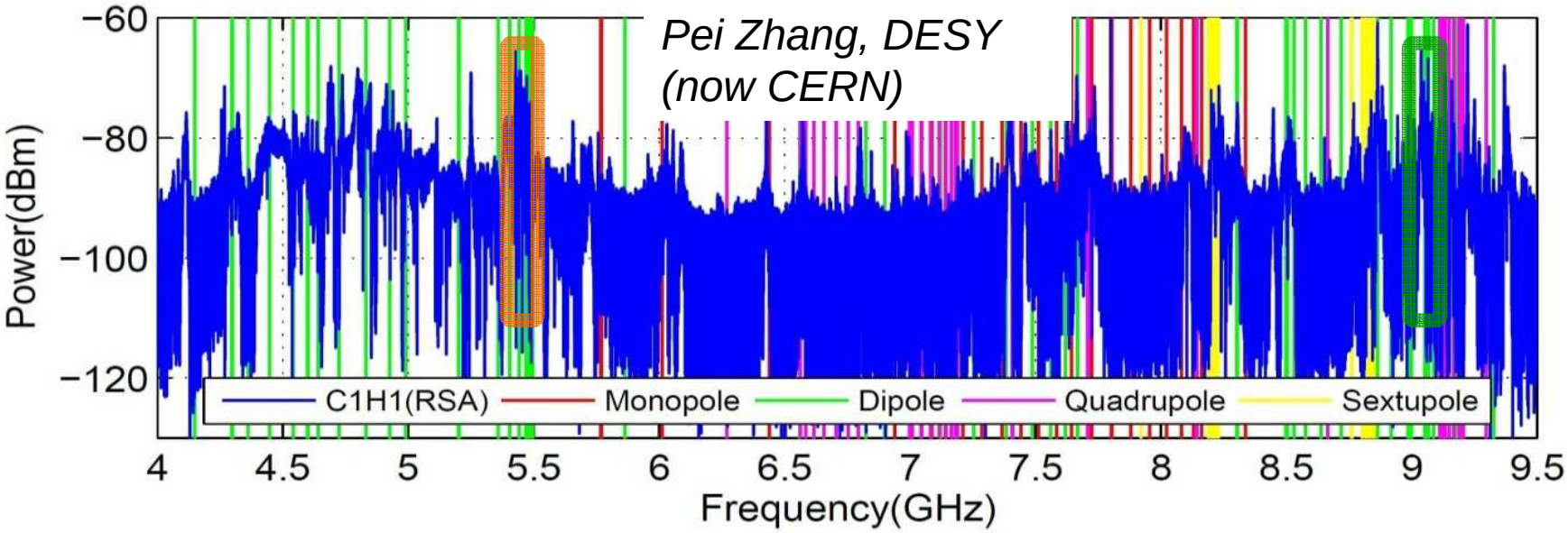


3.9 GHz Cavities: Propagating and Trapped Modes

- Concept based on extensive studies within EuCARD
  - UMAN, UROS, DESY



Dipole band	Beam Position meas.	Resolution (rms)
2nd, ~5.4GHz	Global position over the module length	~20 μm
5th, ~9GHz	Local position in each cavity	~50 μm

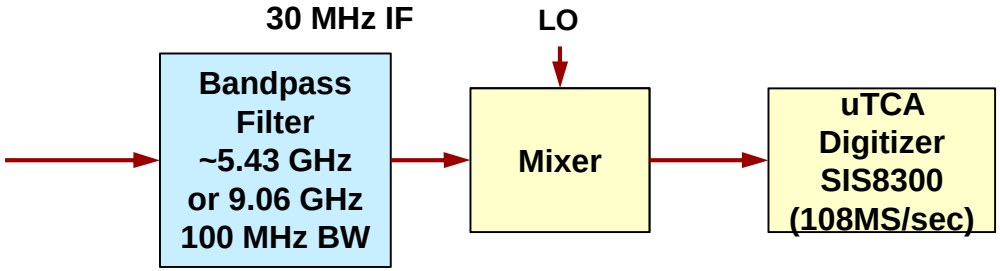


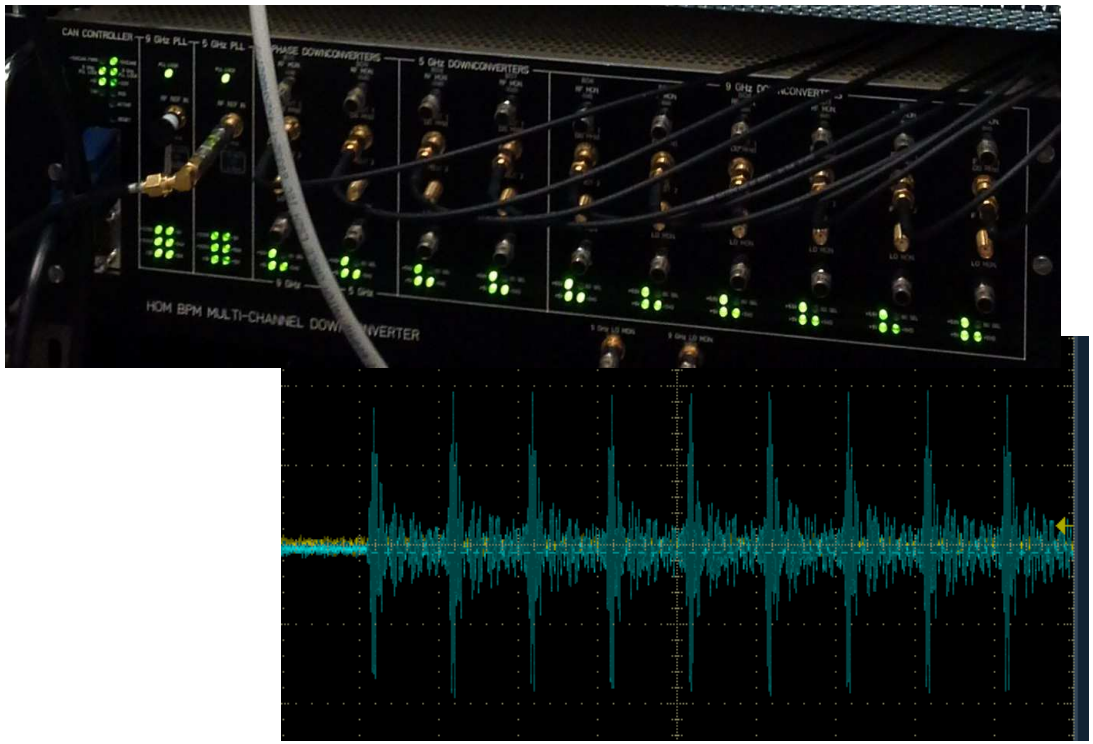
3.9 GHz Cavities: Electronics for FLASH and E-XFEL

- Based on same principle

Installed at FLASH

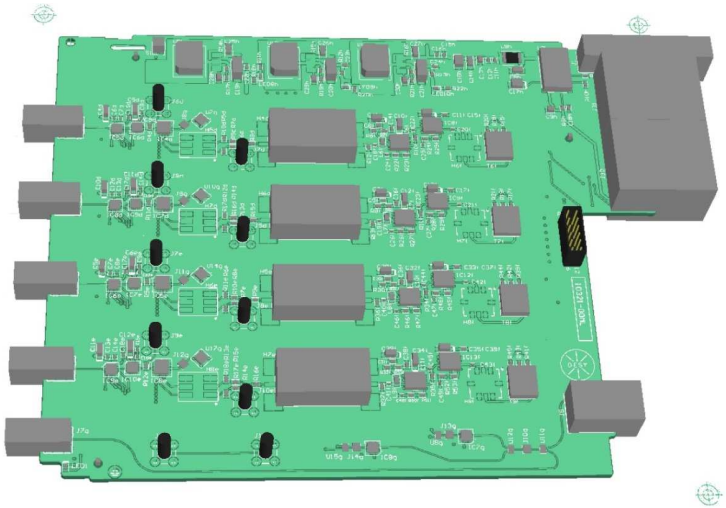
Nathan Eddy, FNAL





Under construction for E-XFEL

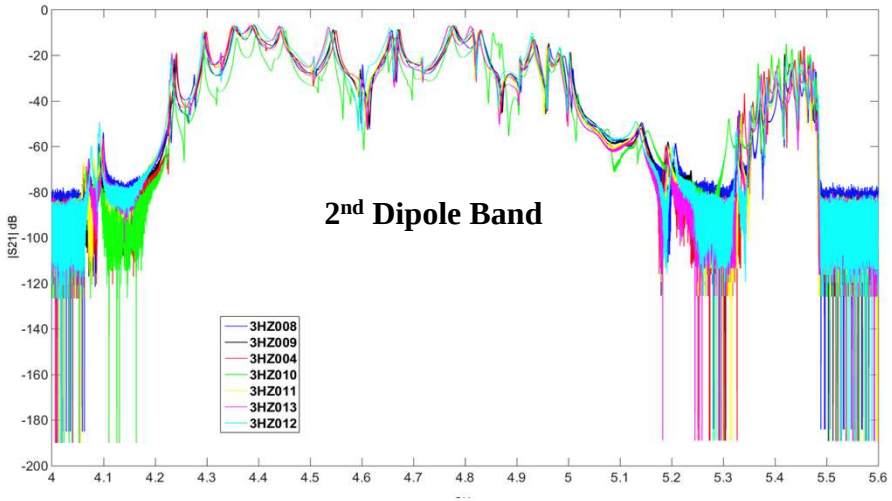
Thomas Wamsat, DESY

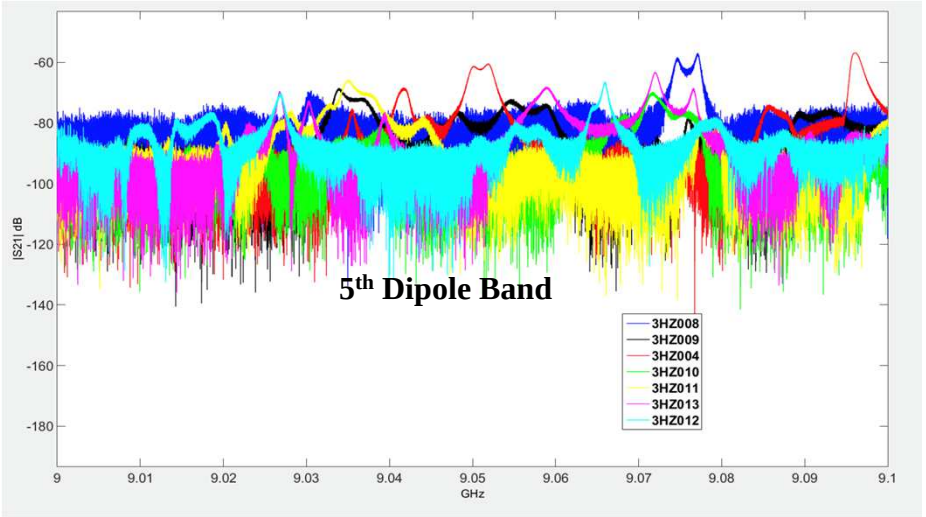


3.9 GHz Cavities at the E-XFEL

- HOM-BPMs at 3.9 GHz cavities at the E-XFEL more challenging due to
  - 8 coupled cavities (4 at FLASH)
  - Different orientation of cavities
- Object of extensive studies within EuCARD-2
  - UMAN, UROS, DESY
- Spectra of individual cavities

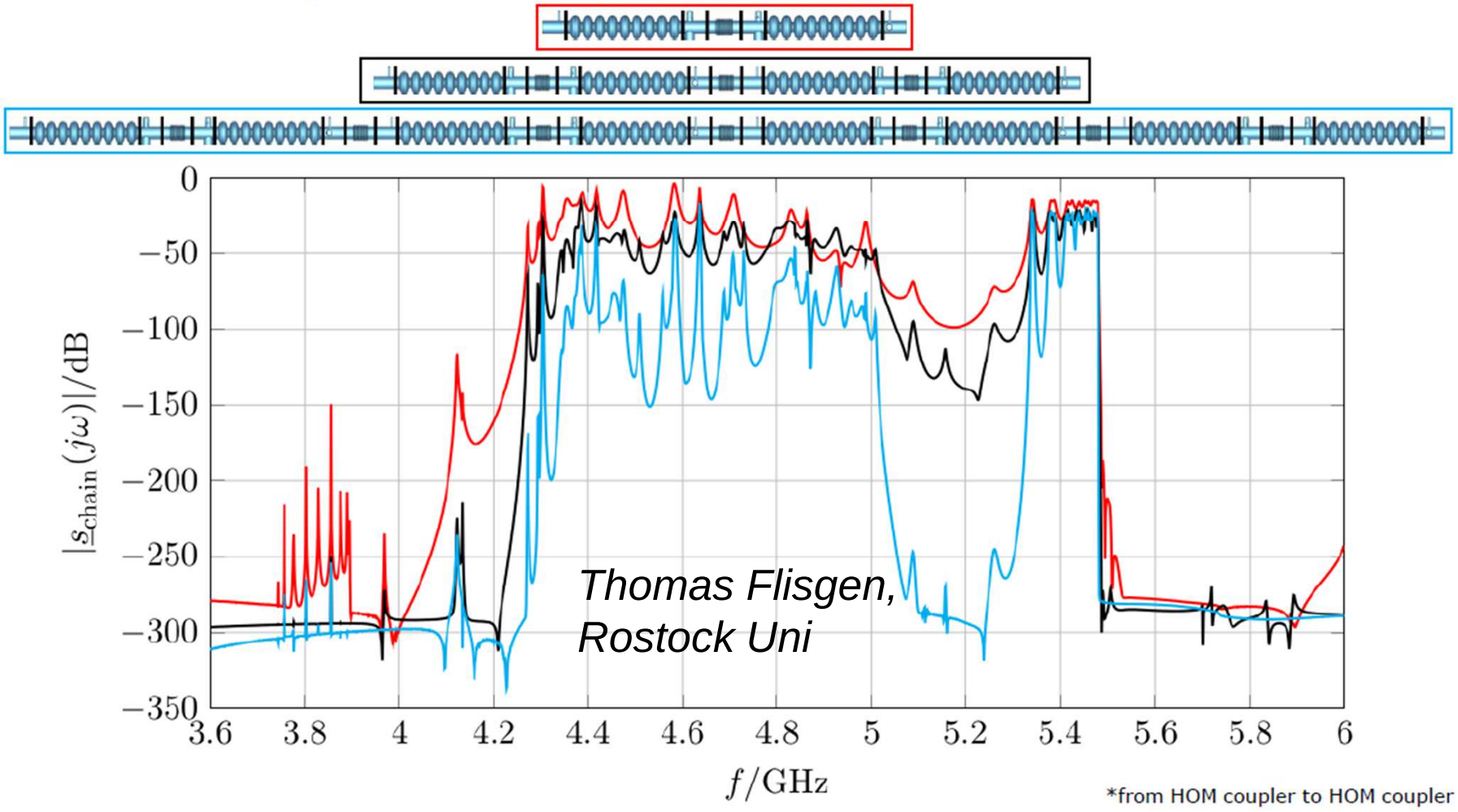
Liangliang Shi, DESY





3.9 GHz Cavities at the E-XFEL

Scattering Transmission via entire Chains*

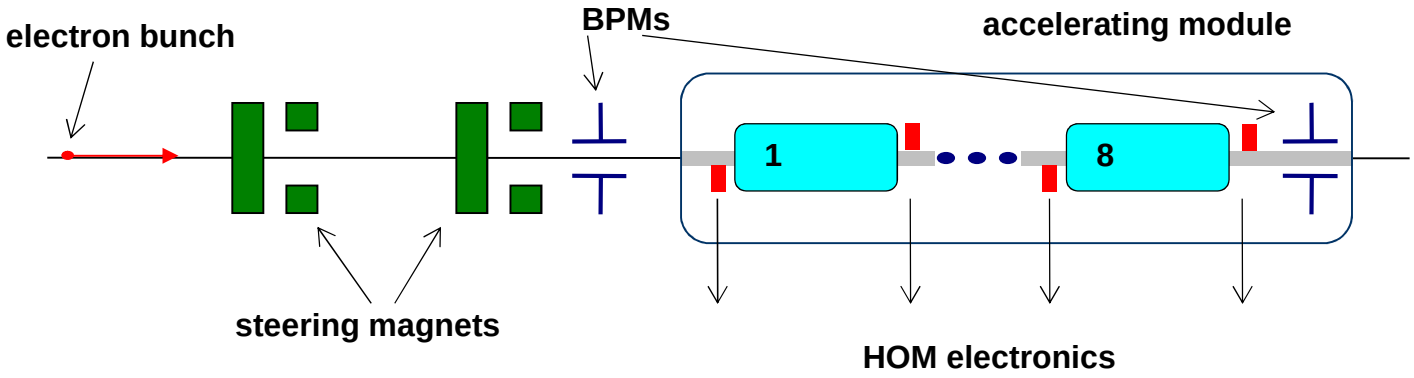


*from HOM coupler to HOM coupler

Stability Issue

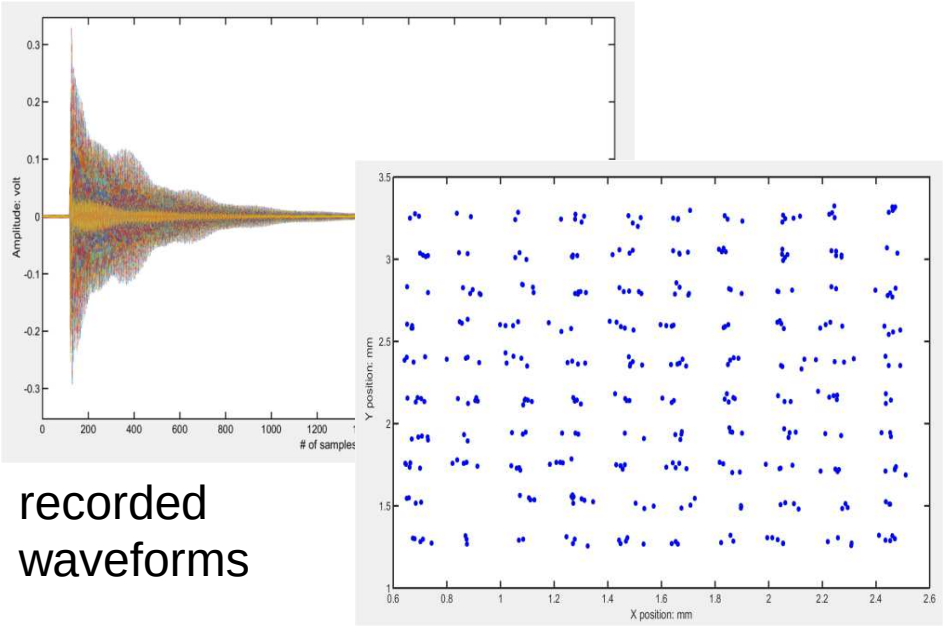
- HOM-BPM calibration drifts away after days
- Resolution degrades dramatically with time
  - No correlation of HOM-BPM results with data from BPMs
- Therefore made extensive study
- Note: The ability to align the beam is not lost

Stability Study: Calibration Procedure



- Find correlation C between HOM signals d and interp. beam positions (X,Y)
  - D usually contains waveforms
  - $D \cdot C = P$ or

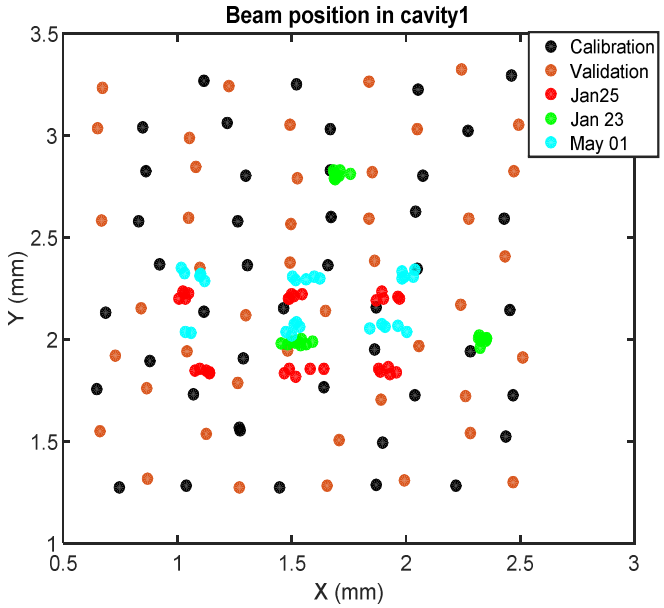
$$\begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} \\ \vdots & \vdots \\ C_{n1} & C_{n2} \end{bmatrix} = \begin{bmatrix} X_{11} & Y_{11} \\ \vdots & \vdots \\ X_{m1} & Y_{m1} \end{bmatrix}$$



recorded waveforms and interpolated beam position in the cavity

Stability study: Results

- Repeatedly took data over time
  - Calibrated with data set
  - Applied calibration to different dates
- Results
  - After careful data pre-processing and using HOM data in frequency domain, we obtained a good stability of results even after months



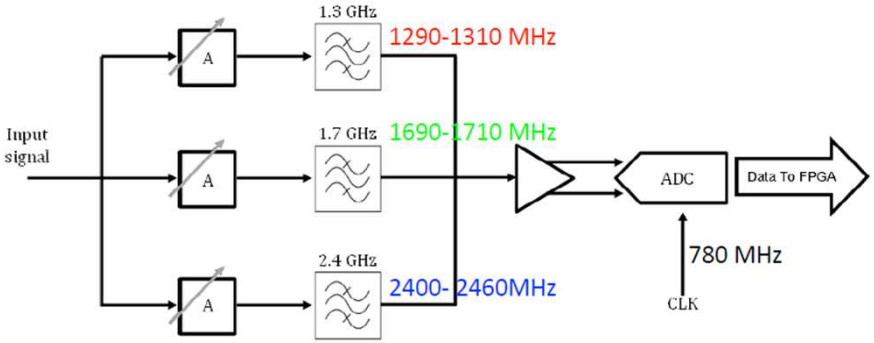
Dates \ Methods	PLS	SVD
January 25 (x, y) (μm)	(3.3, 1.5)	(4.1, 3.3)
January 23 (x, y) (μm)	(2.5, 1.8)	(3.4, 4.4)
May 1 (x, y) (μm)	(4.0, 1.7)	(4.5, 3.0)

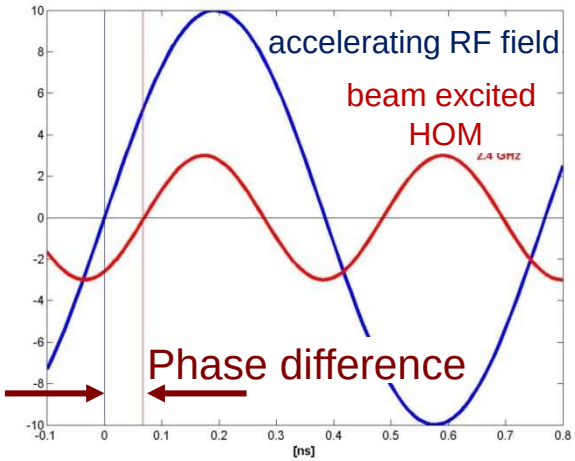
Liangliang Shi, DESY

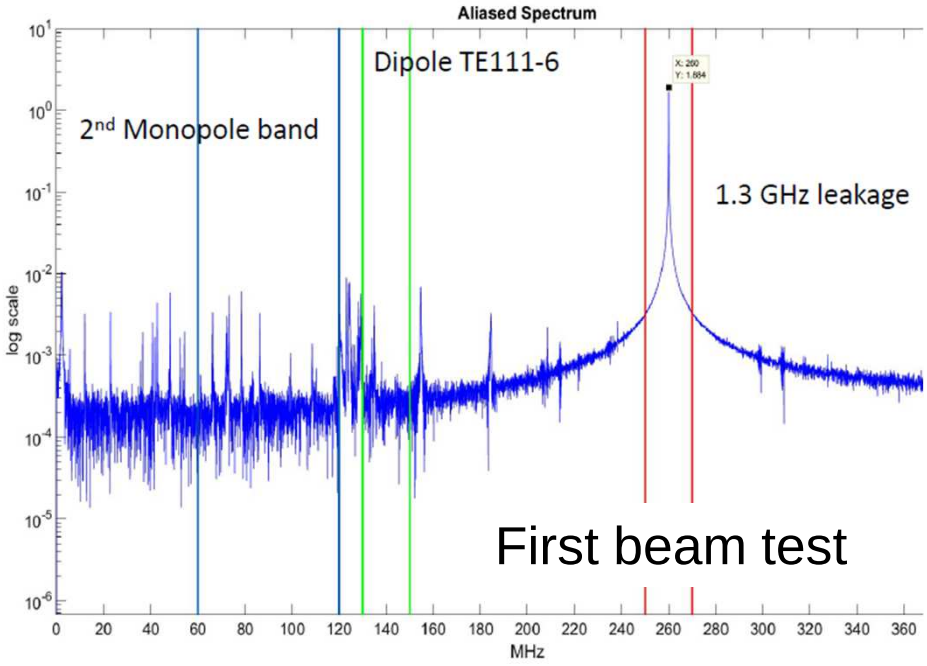
- Note: Directly using data in time domain gives unacceptable RMS degradation over time.

Electronics for 1.3 GHz Cavities @ E-XFEL

- Multiple filter
  - selects 1.3 and 2.4 GHz monopole modes from the HOM spectrum
  - Also 1.7 GHz dipole mode for beam position monitoring
- Direct sampling
  - No downconverting

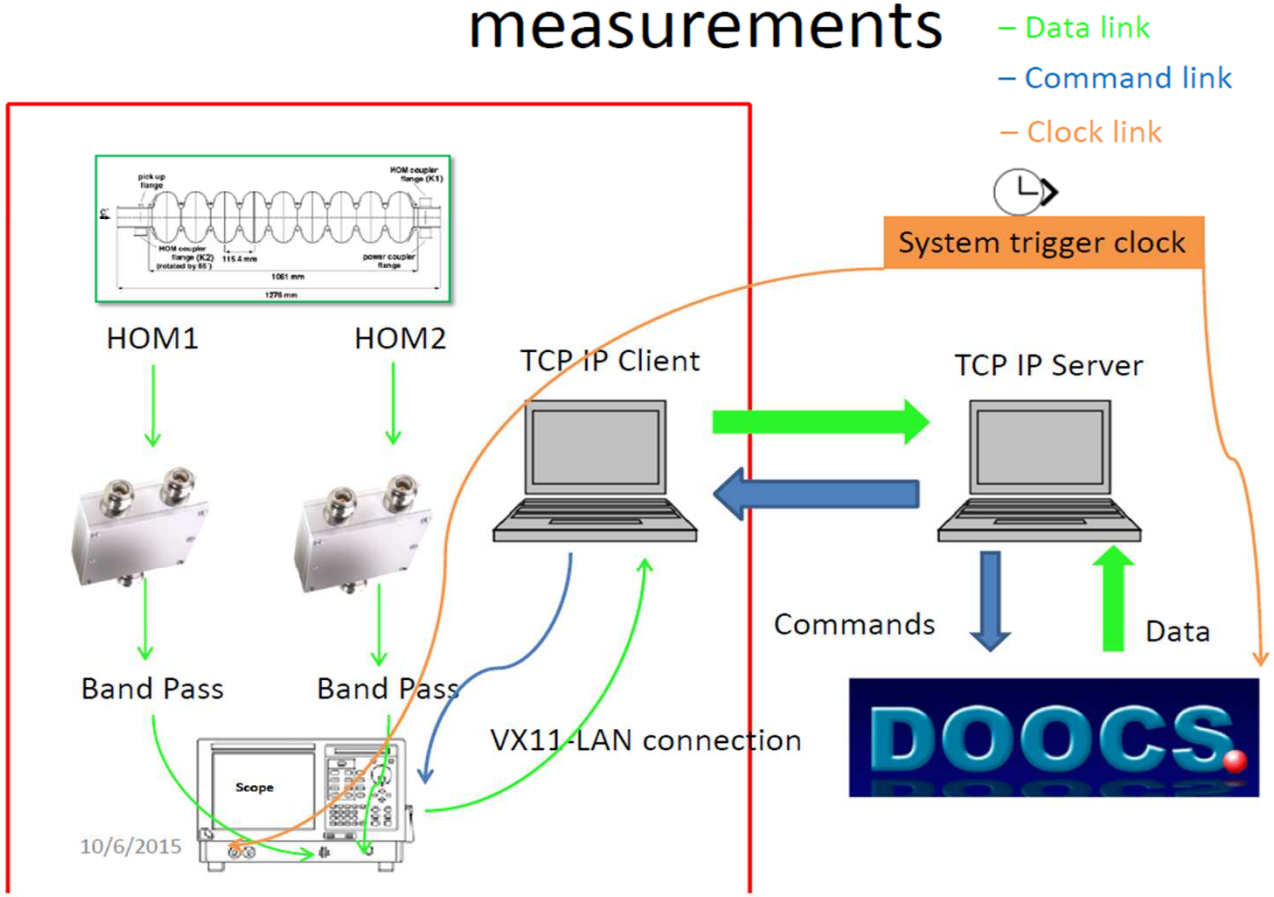






Planned Beam Tests

Setup for the beam phase measurements



Summary

- Useful diagnostics
  - HOM-based diagnostics comes at relatively little cost, with no additional vacuum components
  - Enables reduction of transverse wakefield effects by beam alignment
  - Can give transverse beam position, like a cavity BPM, though with more complex data processing
- Various monitors built or being built for FLASH and the E-XFEL, for 1.3 and 3.9GHz cavities
  - Challenges at 3.9 GHz cavities due to cavity coupling, higher frequency
  - Extra challenges at the E-XFEL: longer cavity-chain, different cavity orientation
- Using careful data preprocessing and spectra instead of waveforms, an RMS error under 10μm was achieved after several months in 1.3 GHz cavities

Acknowledgements

- Talk based on work of many people from several institutes
  - SLAC
  - CEA
  - FNAL
  - University of Rostock
  - University of Manchester
  - Cockcroft Institute
  - DESY
- Part of the work is currently made under EuCARD-2, Grant Agreement 312453
  - WP12 RF Technologies; Task 12.4 HOM-based Diagnostics
    University of Manchester/Cockcroft Institute, Rostock University, DESY

Thank you for your attention!