Analysis of Cavity BPM Data from ESA T474 Experiment

Johnny Ng

with
Chris Adolphsen, Zenghai Li, Mike Woods, et al.

SLAC ILC R&D Meeting, 10/8/07

Outline

- Introduction
- Review of Results from 2006/2007
- Objectives for this Work
- Some Preliminary Findings
- Summary and Next Steps

ILC Prototype S-Band BPMs and the T474 Experiment

- **ILC SC Quad and RF BPM**

  (C.Adolphsen, SLAC-PUB-12046, Aug. 2006)

  – Beam-based alignment of the quads to preserve small emittance
  – Require large aperture BPMs with micron-level resolution
  – Good stability: magnetic center of quad is measured relative electrical center of BPM as the field strength is changed

- **BPM-based Energy Spectrometer (T474)**

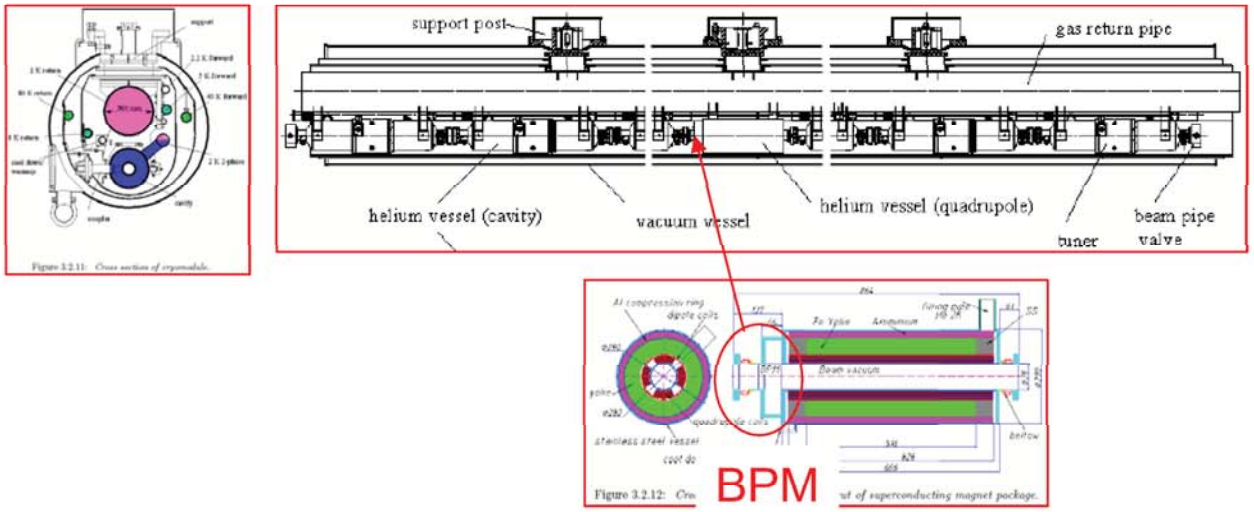
  – Demonstrate mechanical and electrical stability at 100-nm level
  – Perform energy measurement in 4-magnet chicane
  – Develop calibration techniques, operational procedures

→ **Experimental tests using ILC-like beams at SLAC End-Station A**

(From Zenghai Li)

Design Consideration

ILC cryomodule

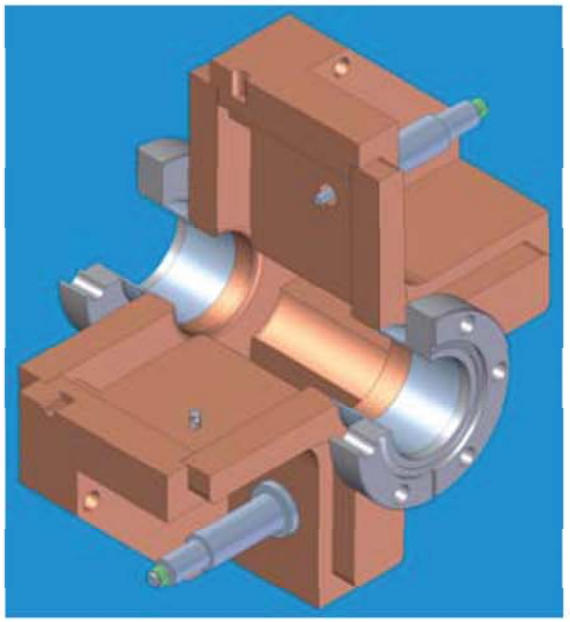


- Need to fit in tight space
- Resolution requirement: 1 μm
- Response time < bunch spacing (300ns) – Q~500-1000
- BPM MUST be easily cleanable
- BPM need be isolated from SC-cavity 3D effects
- Choice of frequency: L or S band
  - –39-mm beampipe radius: L-band will be the choice
  - –17.81-mm beampipe radius: either S or L band

(From Zenghai Li)

S-Band Cavity BPM Prototype

Frequency (GHz)	2.856
External Q	553
Beam pipe radius (mm)	17.81
Cell radius (mm)	60.0
Cavity gap	10.0
Waveguide radial dimensions (mm)	70.0
Waveguide axial dimension (mm)	75.0
Waveguide height	10.0



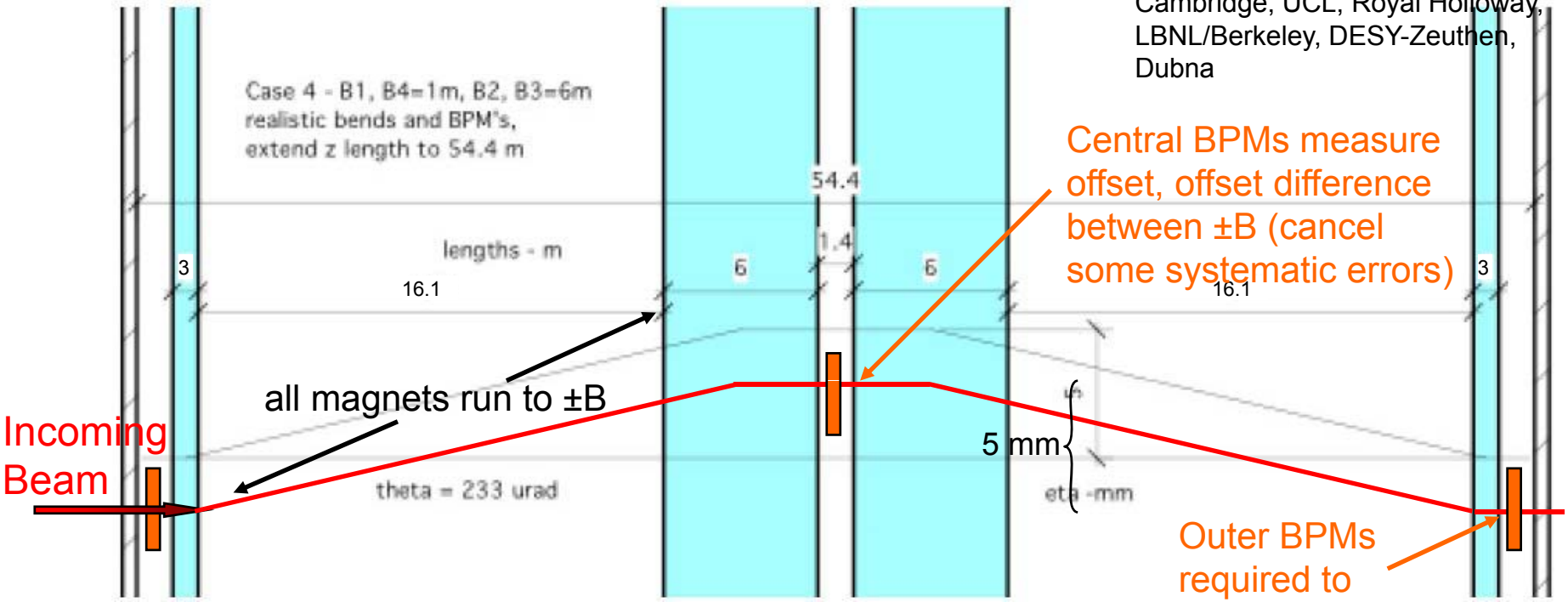
- 3 S-band BPM cavity being manufactured
- Preliminary measurement was performed on one of the prototypes

⇒ Theoretical resolution on the order of 1.5 nm/nC

BPM-based Energy Spectrometer

- Pure "Displacement" Strategy: Prototype Design

M. Hildreth (Notre Dame), SLAC, Cambridge, UCL, Royal Holloway, LBNL/Berkeley, DESY-Zeuthen, Dubna

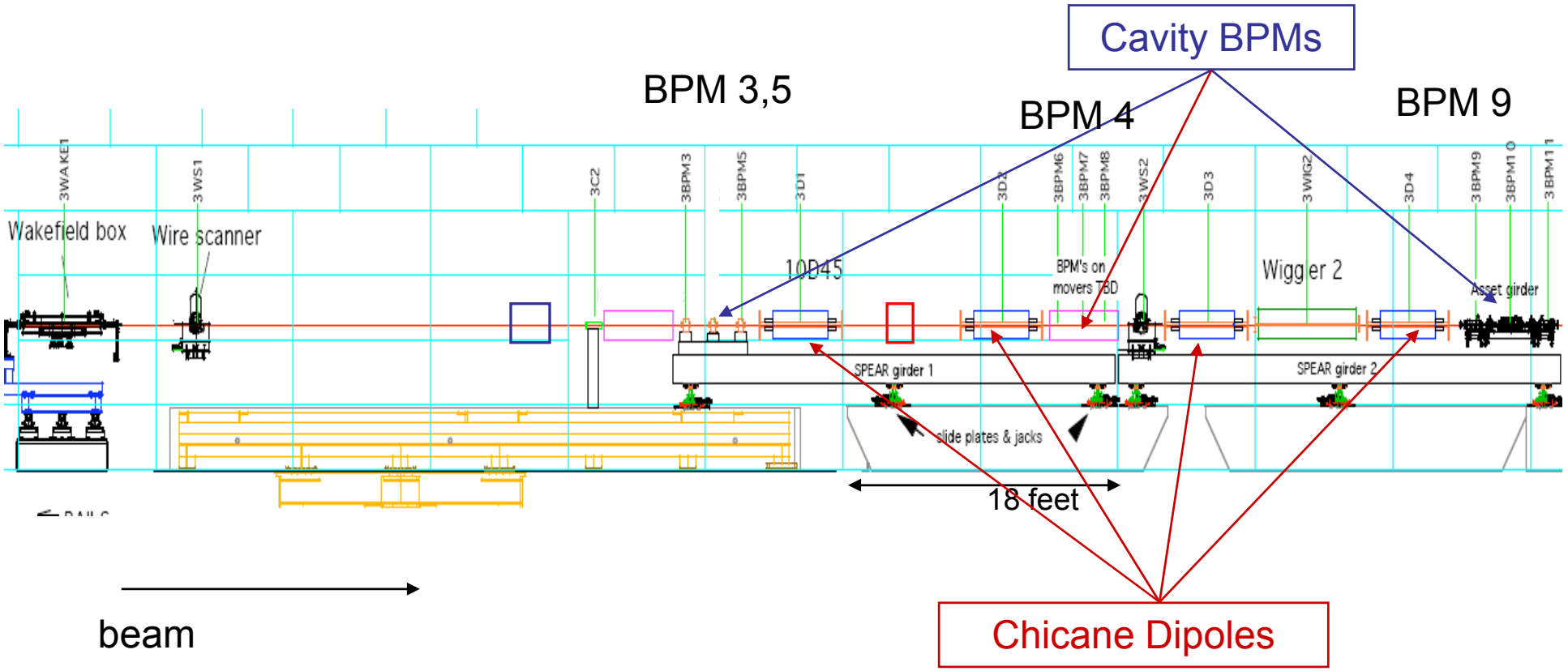


  - total length 54.4 m
  - dispersion at center = 5mm (~equal to beam displacement)
    - so, 0.5μm BPM resolution gives 1×10^{-4} measurement (per pulse)
  - Design incorporated into RDR BDS Lattice

better resolution would allow intra-train bunch energy measurements

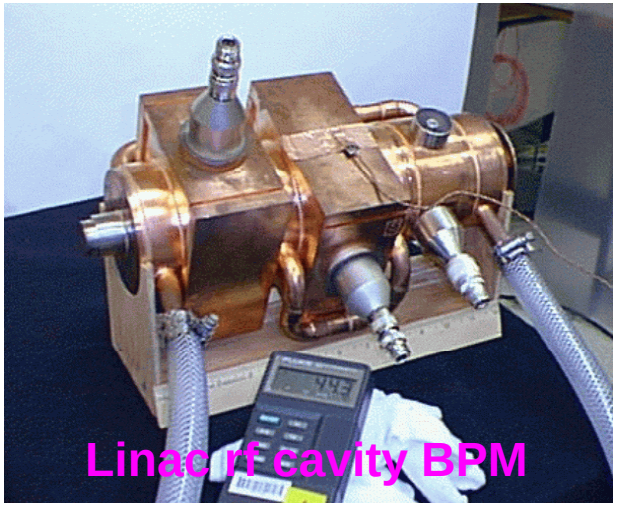
(from Mike Hildreth, June 17,2007)

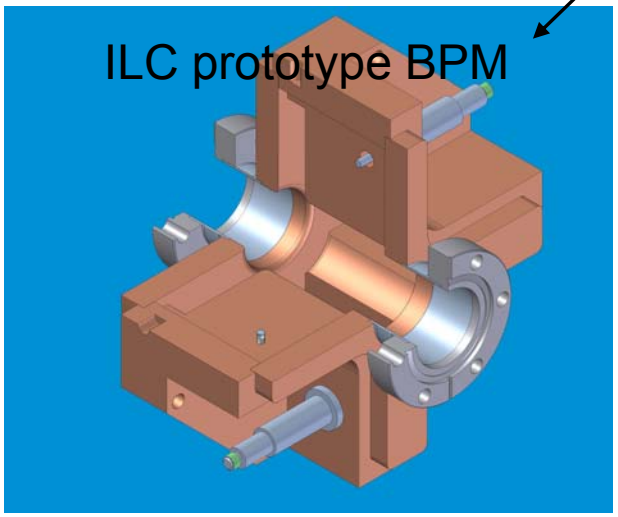
ESA Equipment Layout



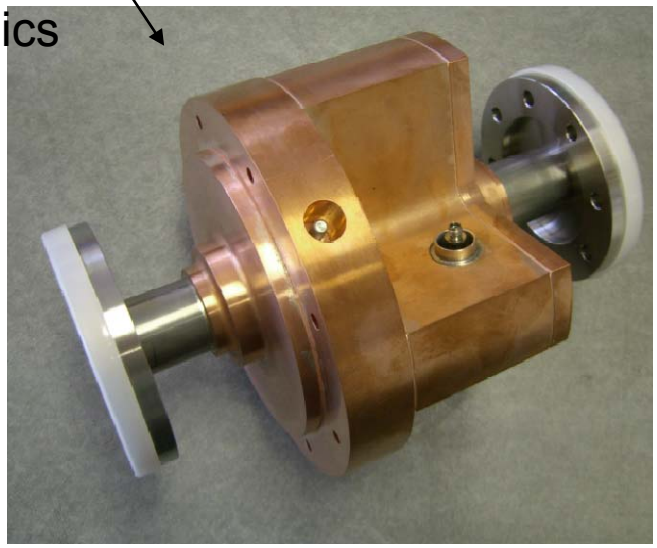
(Based on Mike Woods talk, ILC R&D Meeting, Sep 10, 2007)

Cavity BPMs and Electronics



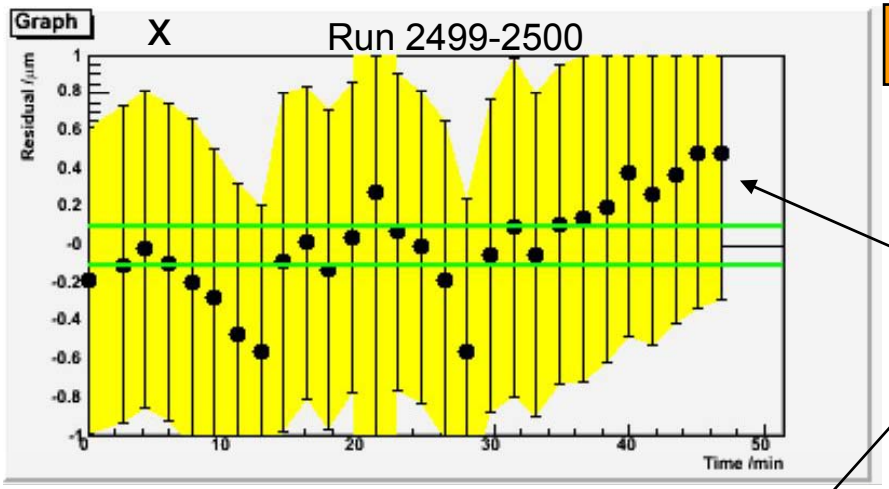


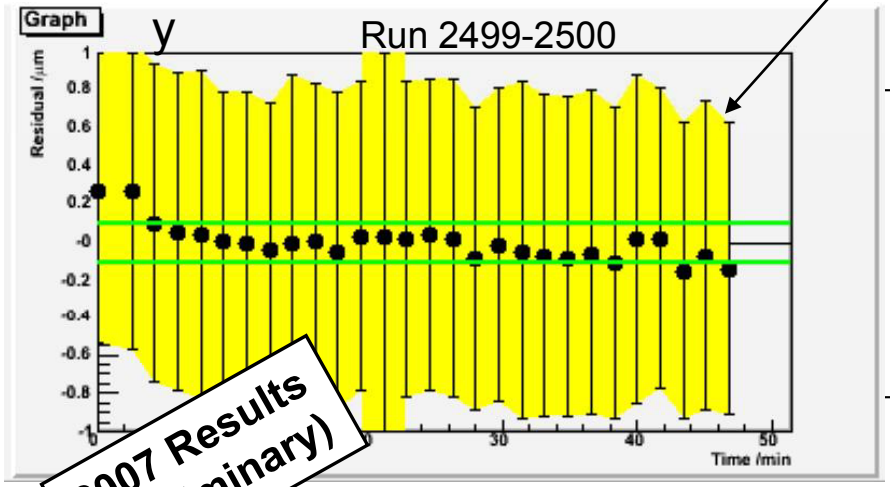
- SLAC Linac BPMs form main component of instrumentation
  - new electronics developed by Y. Kolomensky (Berkeley/LBNL)(LCRD Accelerator R&D)
- Also testing prototype ILC Linac BPMs developed at SLAC (C. Adolphsen)
- New BPMs, optimized for energy spectrometer, designed at University College London in collaboration with BPM experts at SLAC and KEK
  - custom electronics
  - mover system
  - July 2007



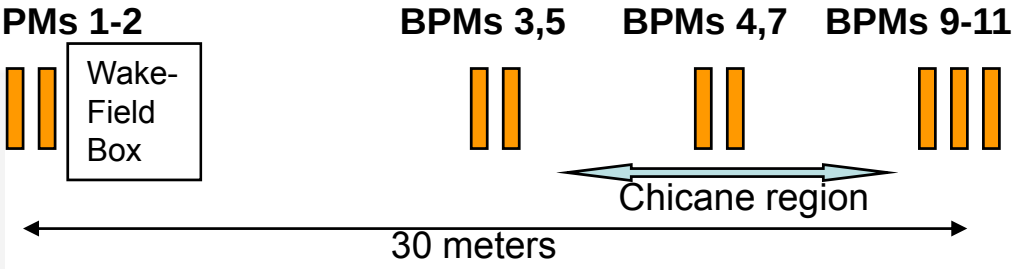
(from Mike Hildreth, June 17,2007)

T474: Resolution & Stability
Linking BPM Stations in ESA





2007 Results (Preliminary)



❖ **use BPMs 1,2 and 3,5 and 9-11 to fit straight line**
- predict beam position at BPM 4
- plot residual of BPM 4 wrt predicted position

*0.5μm → 100 ppm
"error" bars shown are rms resolution

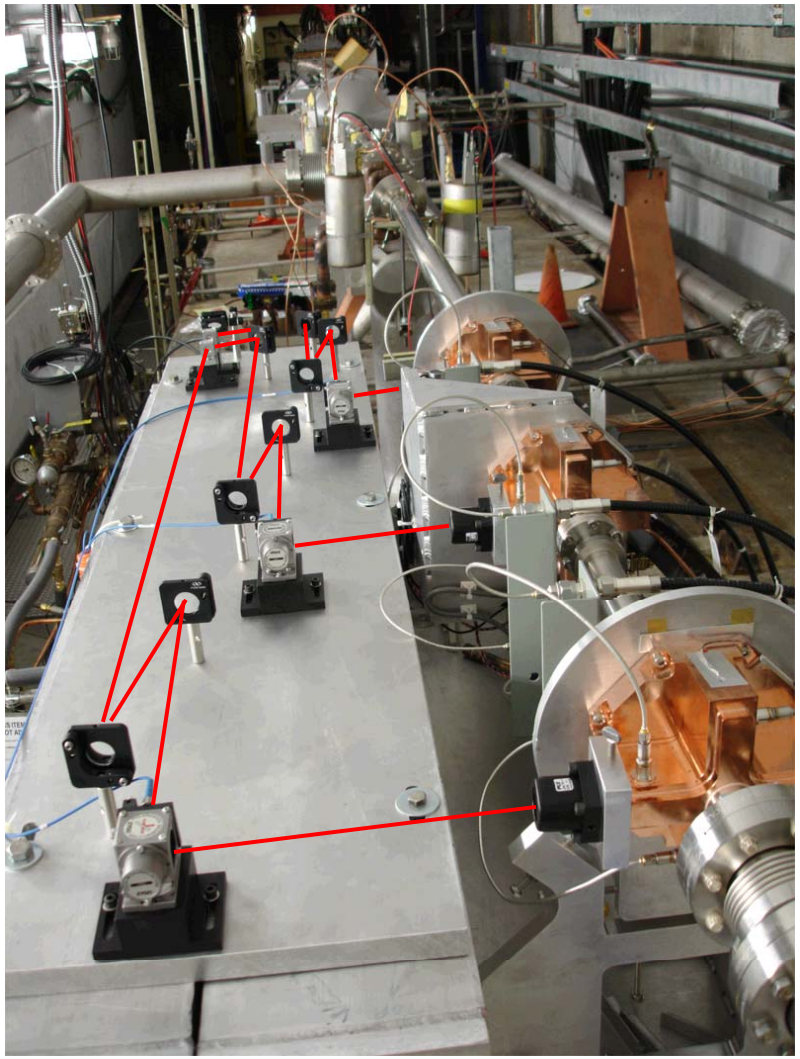
→ a primary purpose of T-474 is to investigate long-term (hours) stability at sub-micron level, and study dependence on beam parameters and environment (temperature, magnetic fields) and electronics stability (calibration tone system important)

→ stability studies very important for ILC Linac BPM and quad magnetic center stability requirements (also of interest for system of 40 RF BPMs for LCLS undulators)

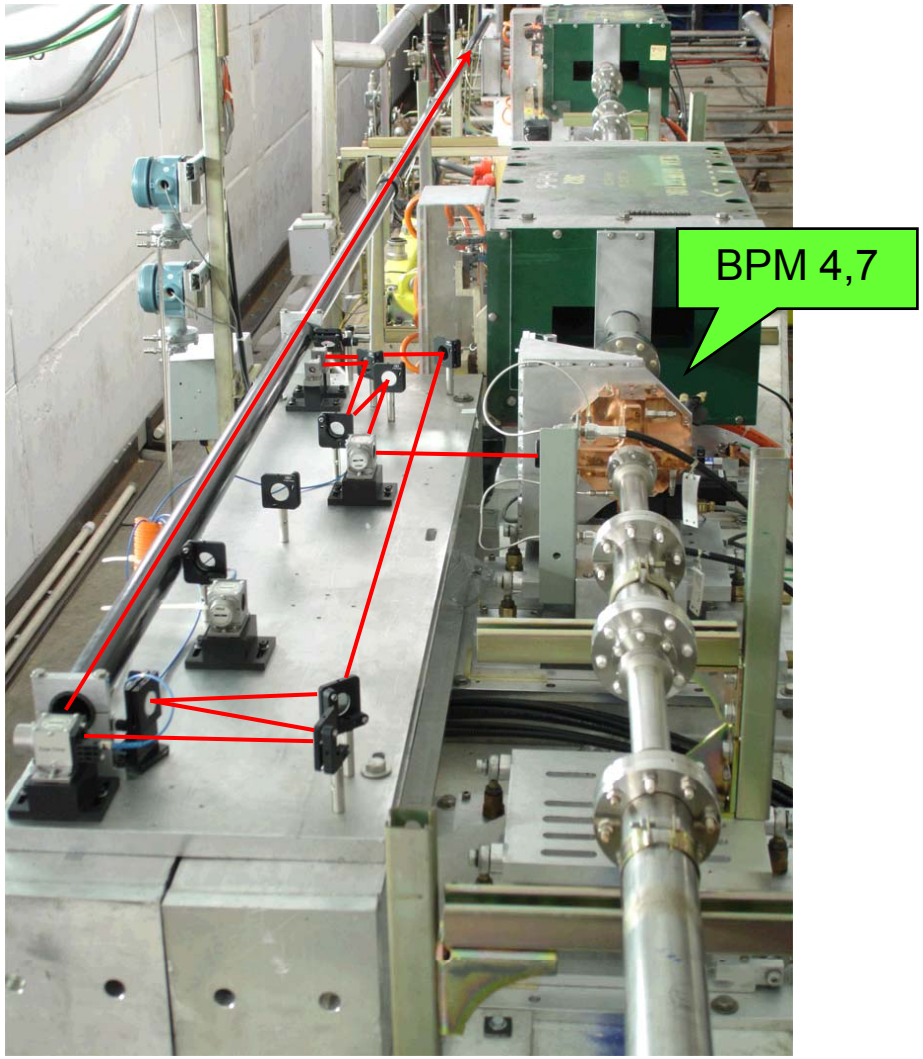
(from Mike Woods talk, ILC R&D Meeting, Sep 10, 2007)

Interferometer Installations

July 2006



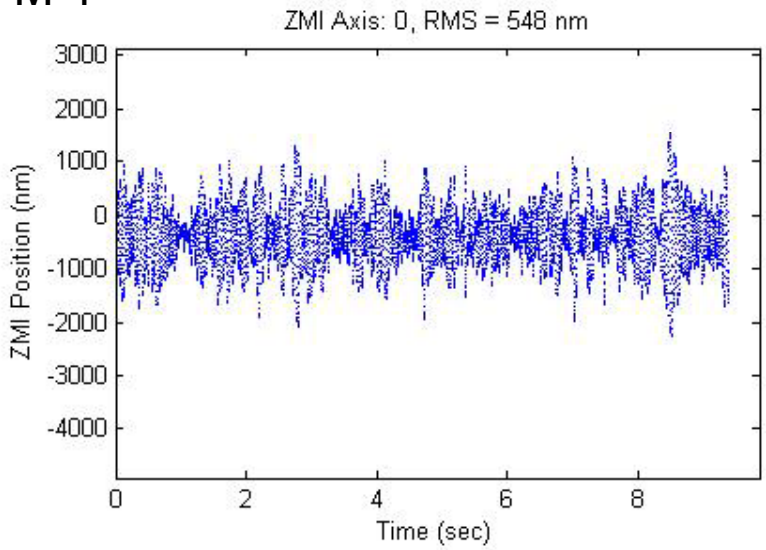
Mar 2007



(from Mike Hildreth, June 17,2007)

Zygo Interferometer measurements of mechanical vibration

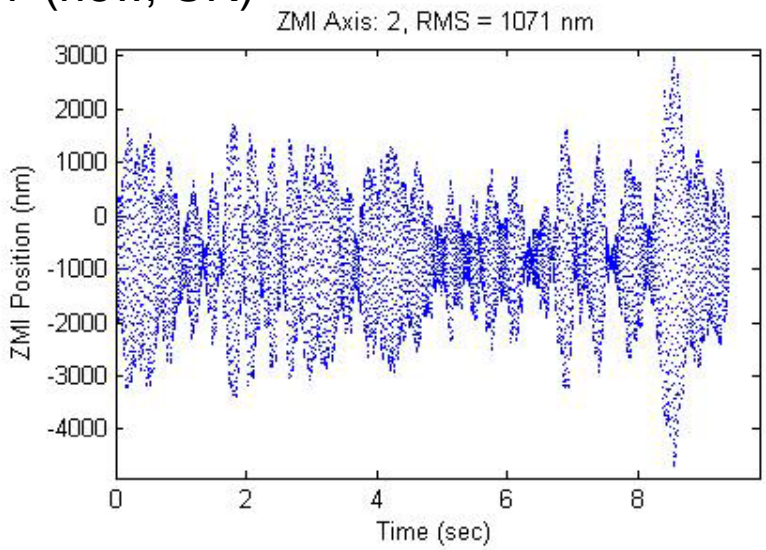
BPM 4



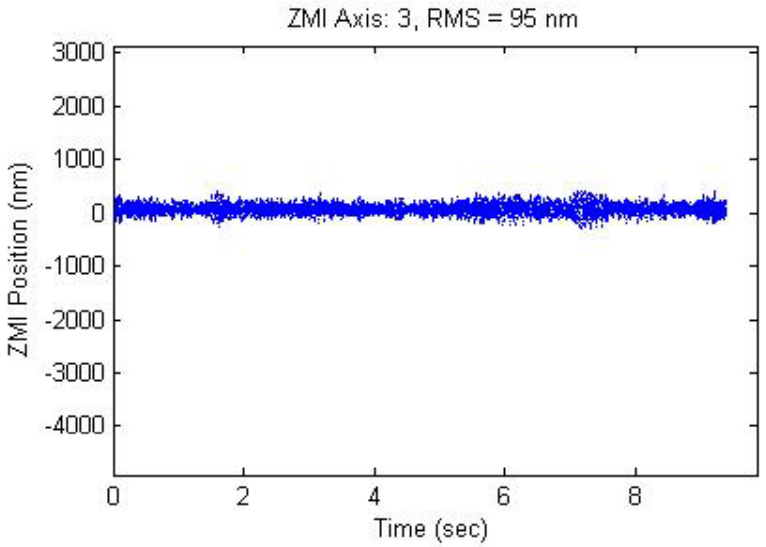
BPMs 4, 7 are on movers

Water flow on.

BPM 7 (new, UK)

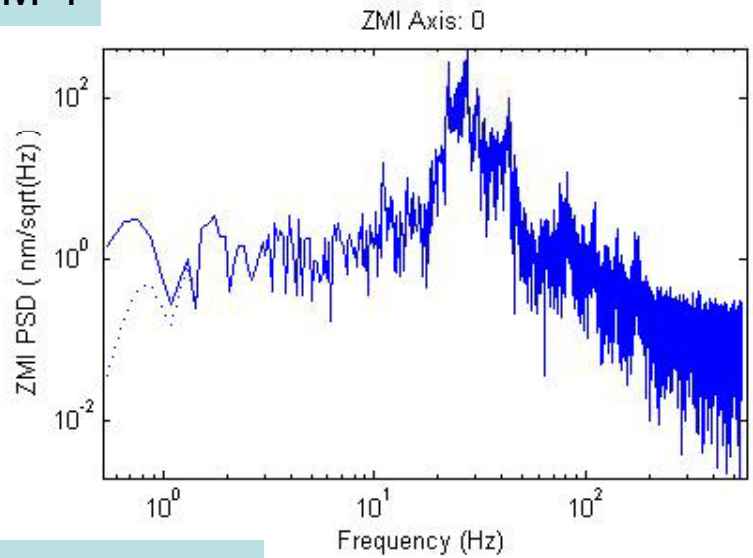


BPM 5



Zygo Interferometer measurements of mechanical vibration

BPM 4

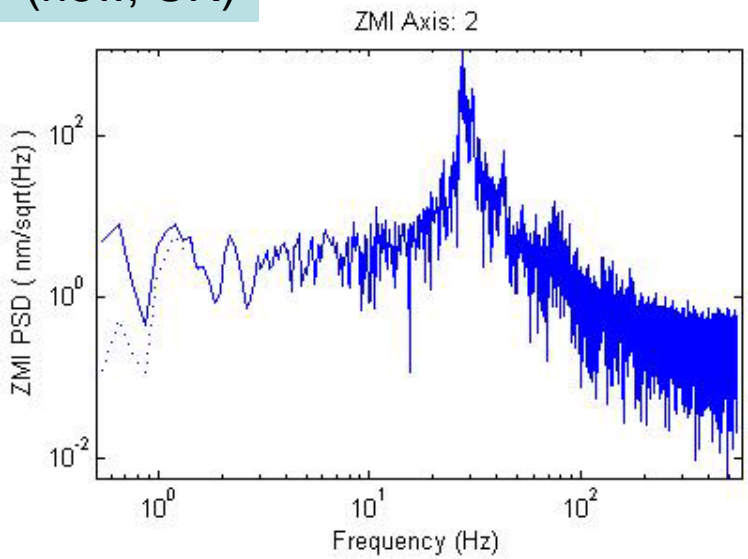


BPMs 4, 7 are on movers

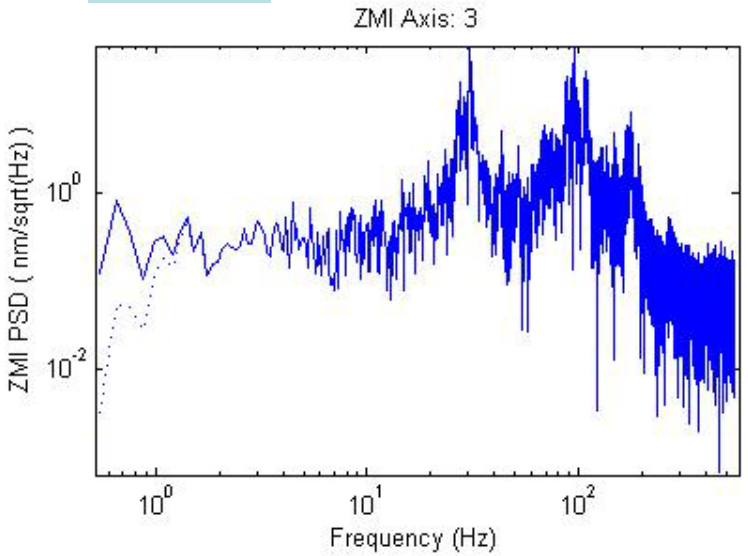
Water flow on.

⇒ Resonance at 28 Hz

BPM 7 (new, UK)

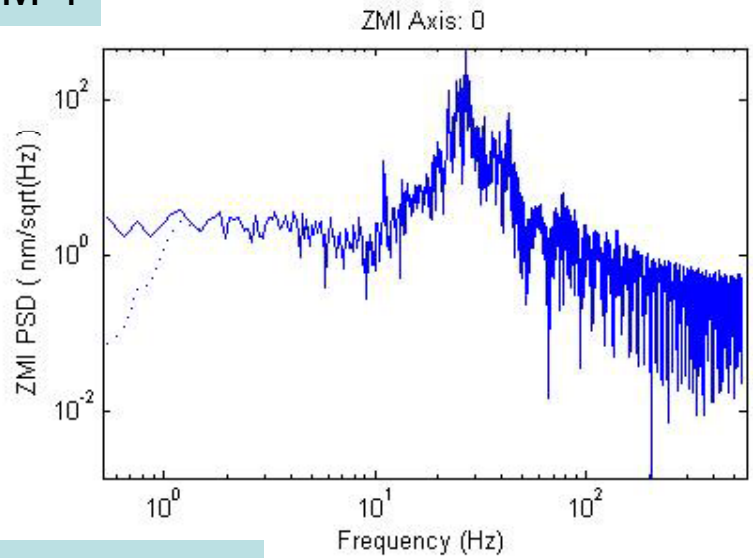


BPM 5



Zygo Interferometer measurements of mechanical vibration

BPM 4

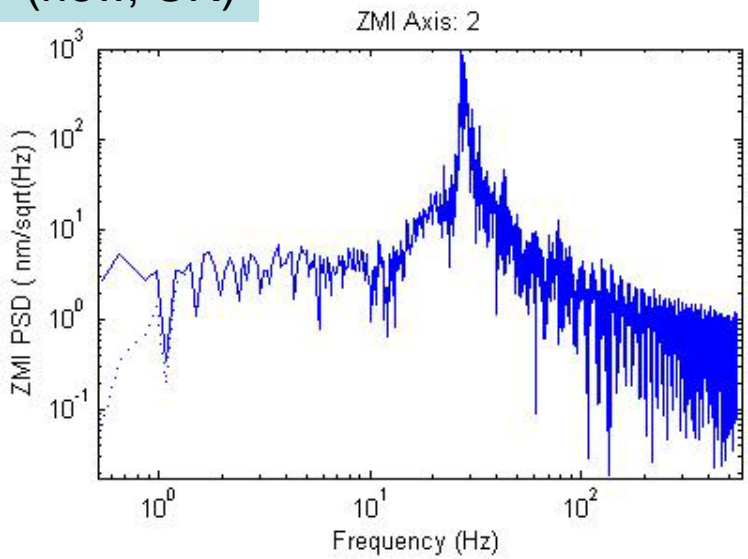


BPMs 4, 7 are on movers

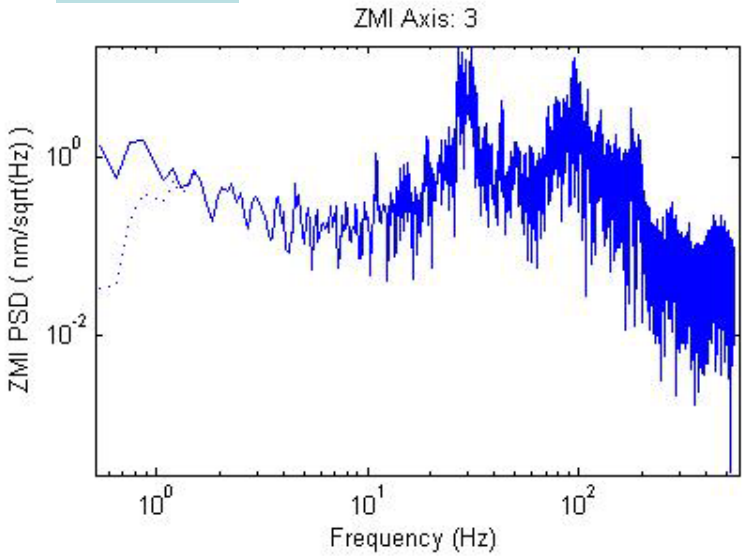
Water flow off

Resonance at 28 Hz remains.
Amplitude reduced by ~12% for BPM 4,7; ~factor of 2 for BPM 5

BPM 7 (new, UK)



BPM 5



Objectives for This Work

- T474 performance encouraging thus far
- Some questions to be addressed:
  - Resolution: why is it worst than expected?
  - Jitter/Drift: what caused it?
  - Mechanical vibration: origin of the 28 Hz resonance?
  - DDC Algorithm: optimized for the ILC BPM?

⇒ Detailed understanding of the systematics and performance issues of the prototype BPM

⇒ Address operational issues:
  - Calibration requirements (how often, what parameters?)
  - Non-invasive calibration: corrector scans? Movers?

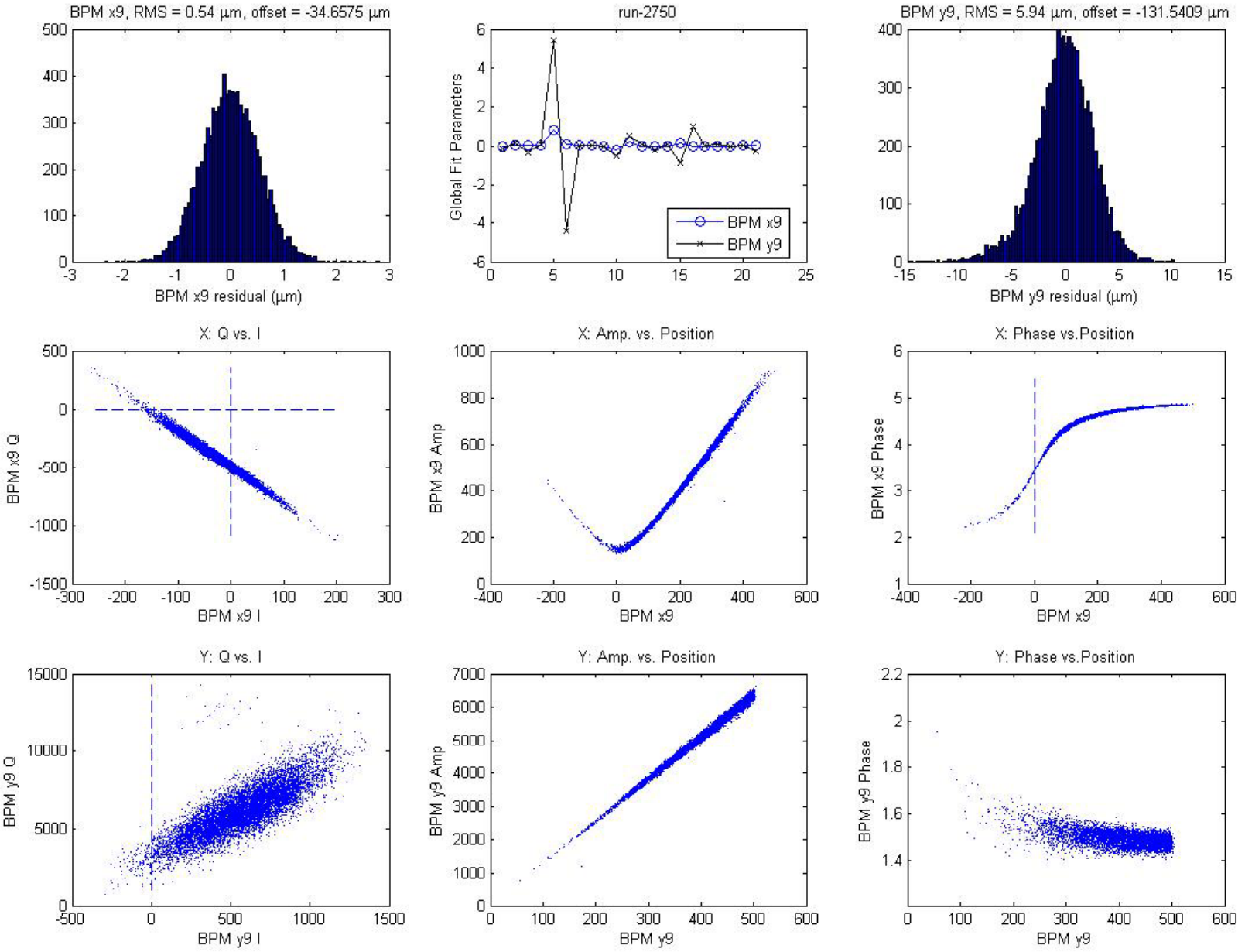
Initial Analysis of T474 Data

- Data set from July 2007 run in ESA
- Basic plan:
  - compare the performance of ILC prototype BPMs and SLAC BPMs which are well-understood
  - Look for potential problems and address them with the help of simulations

⇒ Start by using existing T474 analysis algorithm

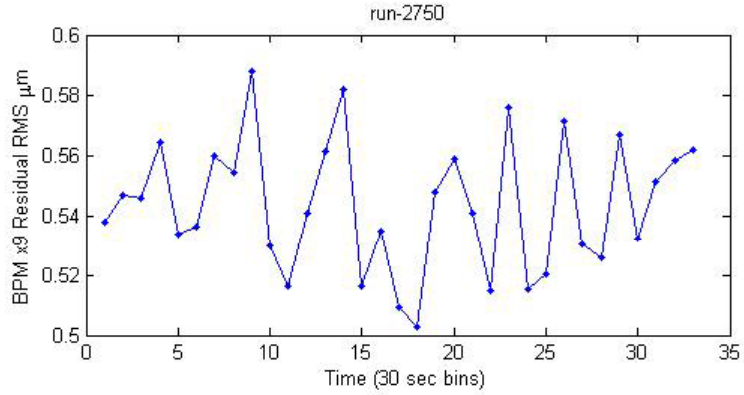
⇒ Then look for trouble in raw data

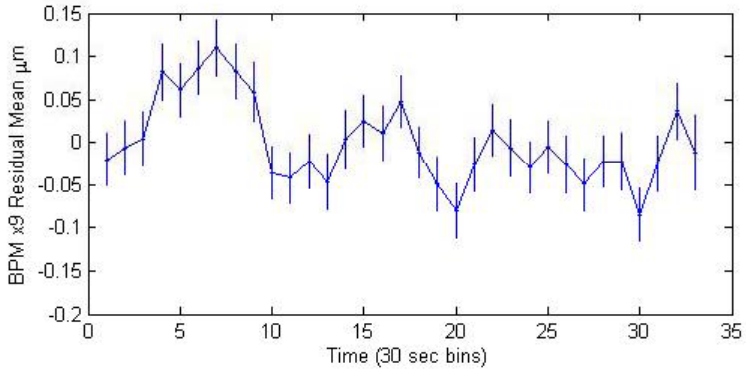
BPM #9 (old SLAC S-Band BPM)

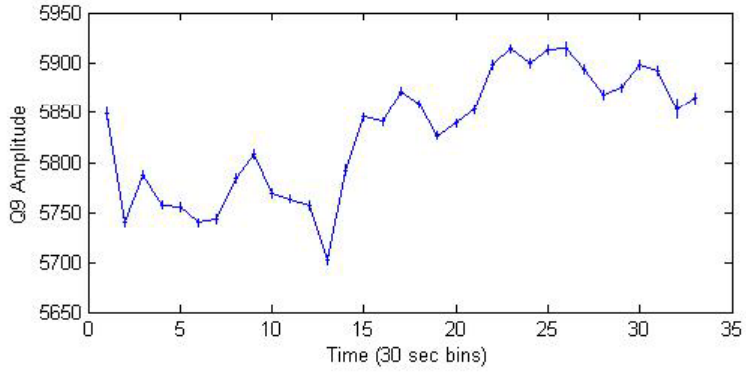


BPM #9 (old SLAC S-Band BPM) - Stability

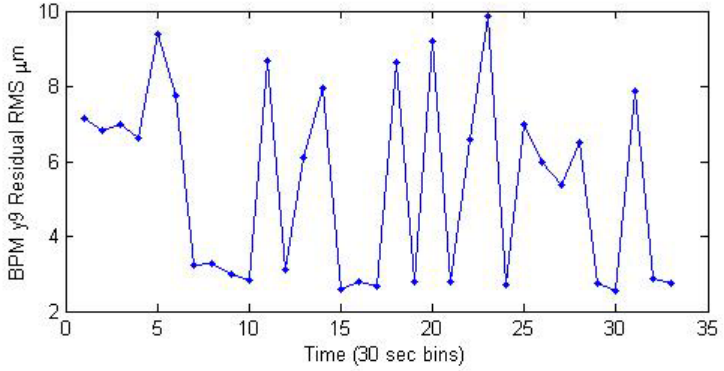
X

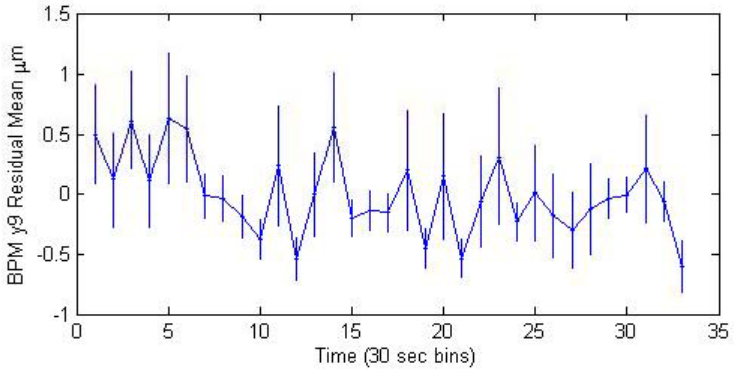


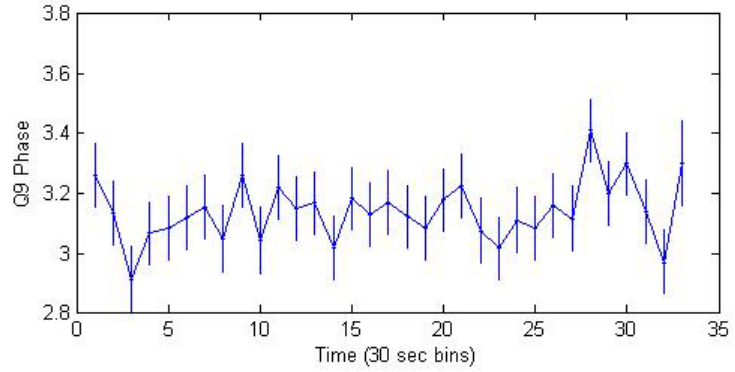




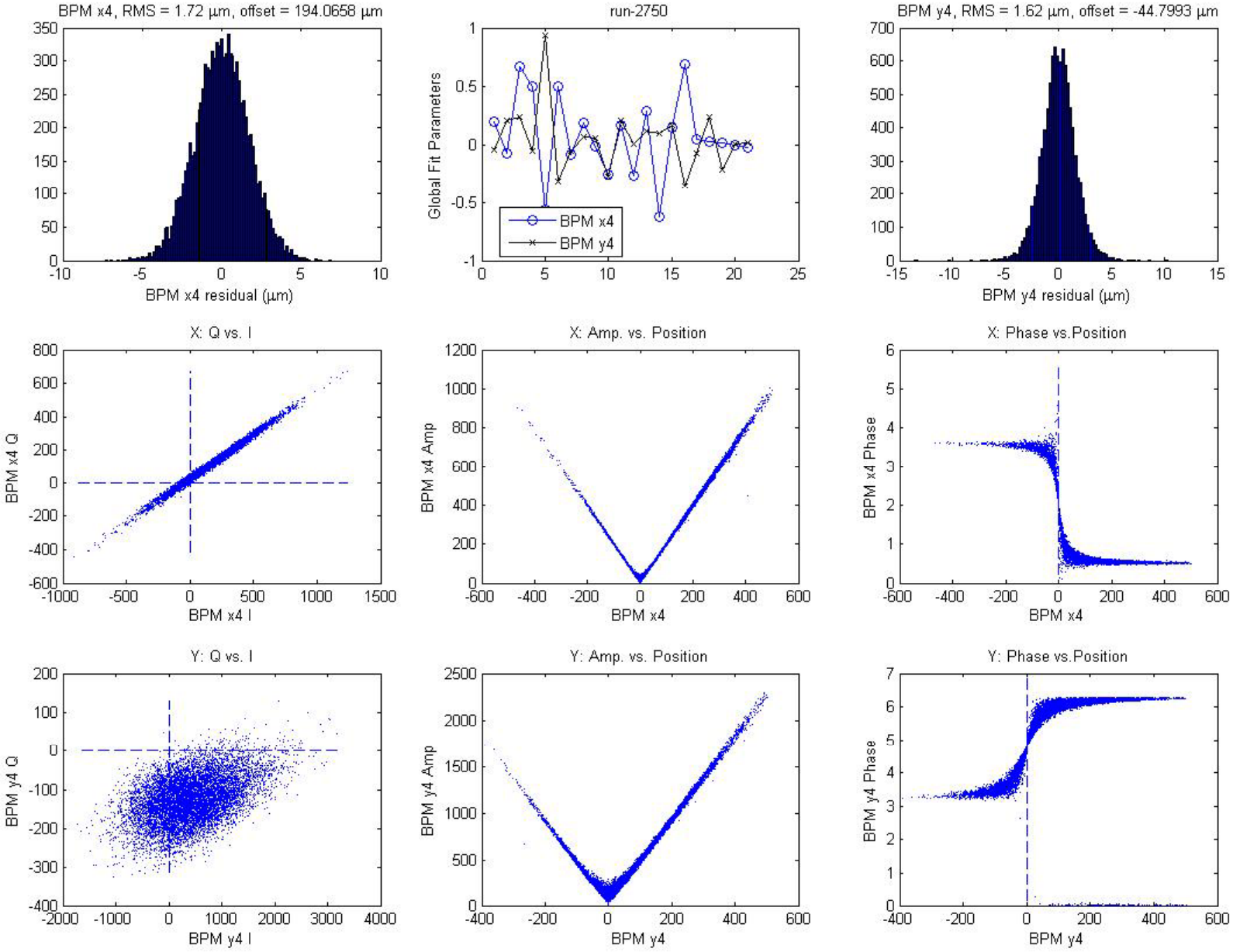
Y



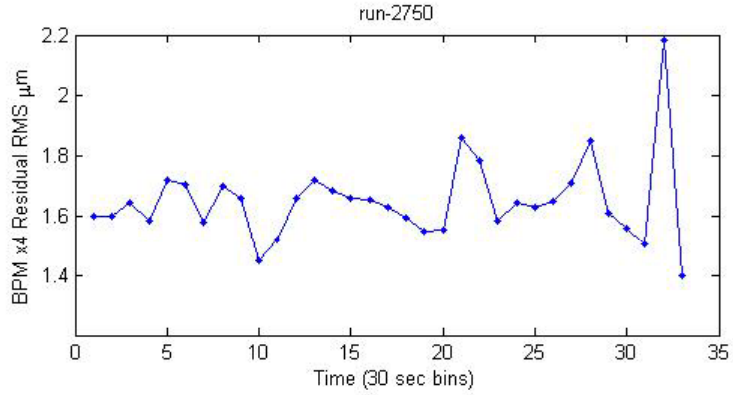


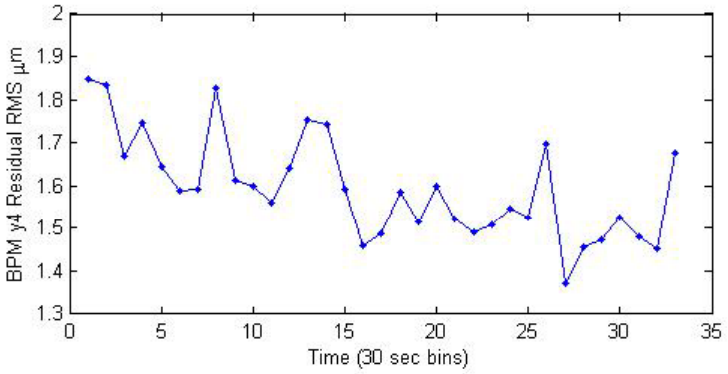


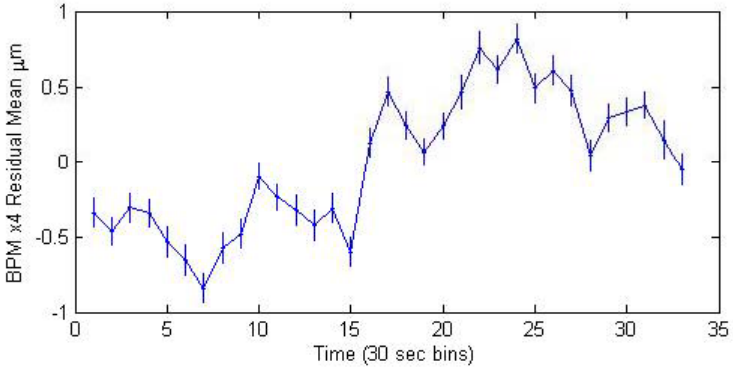
BPM #4 (ILC Prototype S-Band BPM)

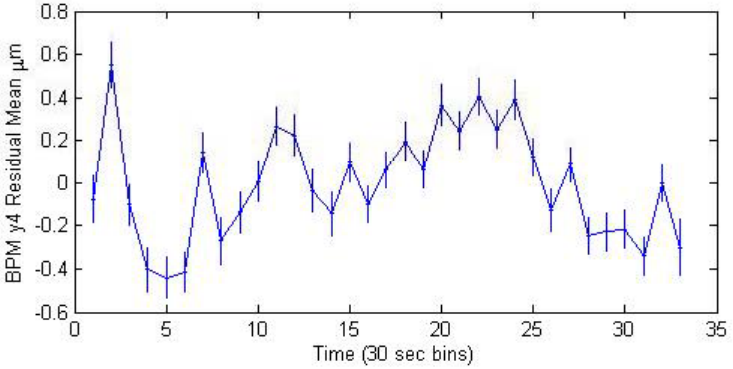


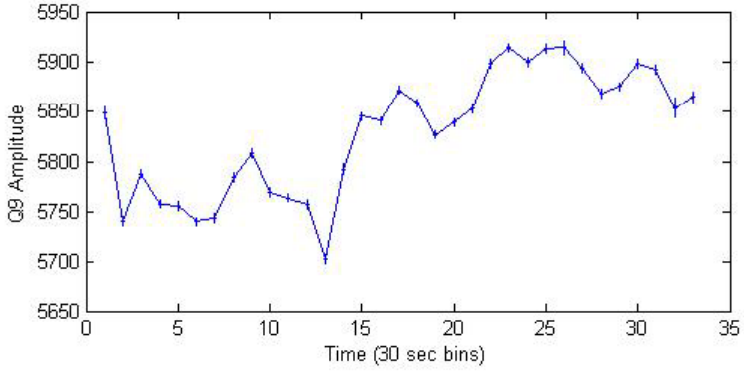
BPM #4 (ILC Prototype S-Band BPM) - Stability

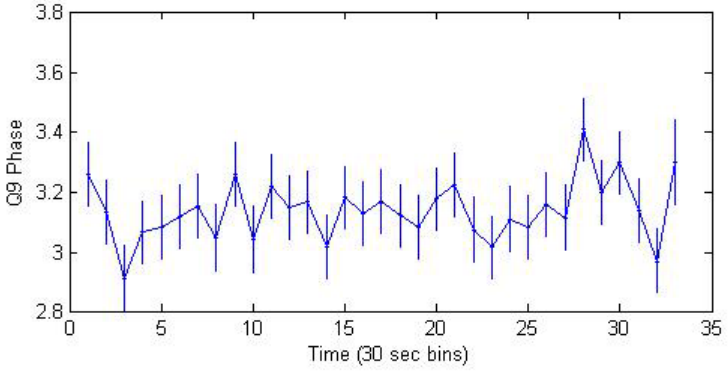




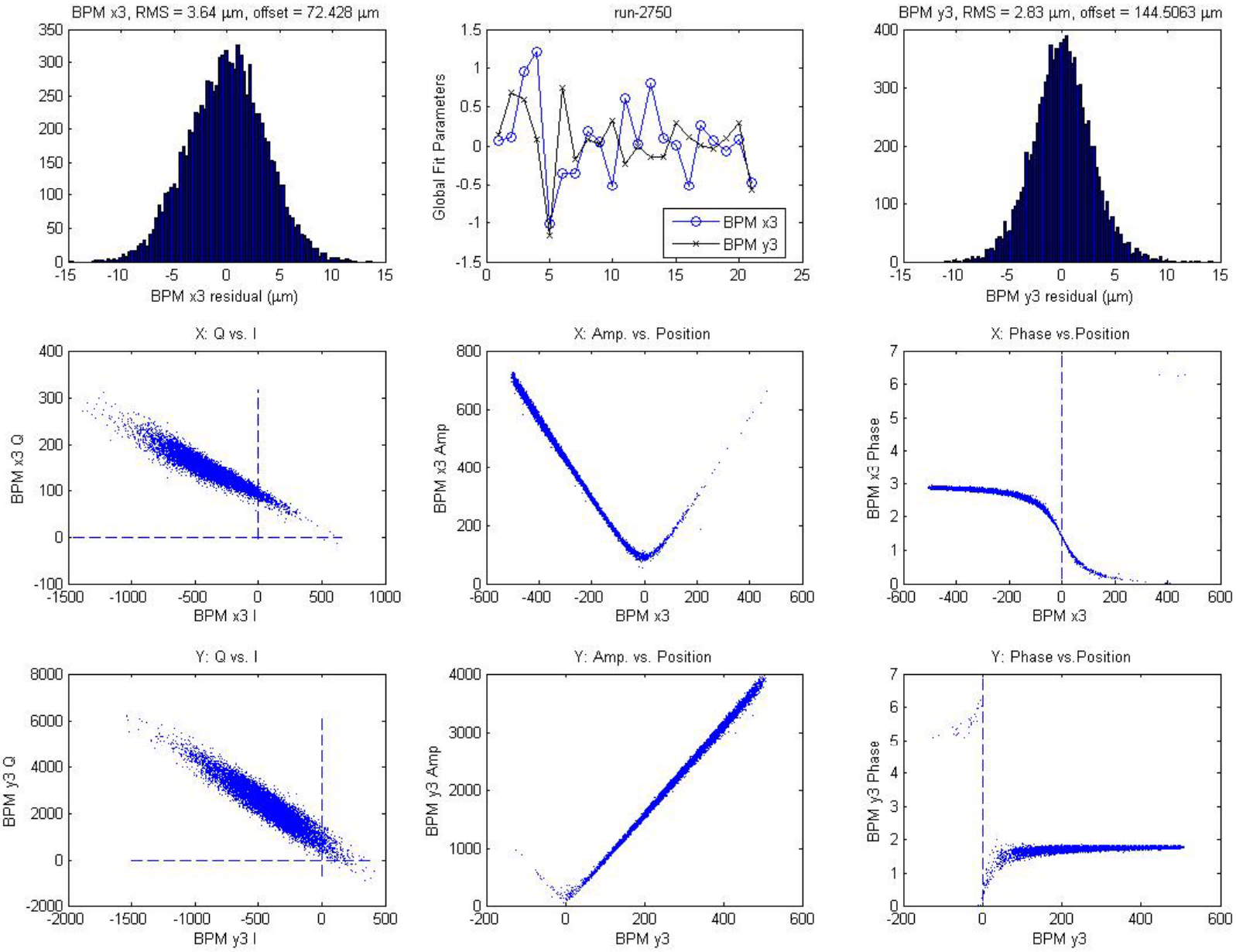




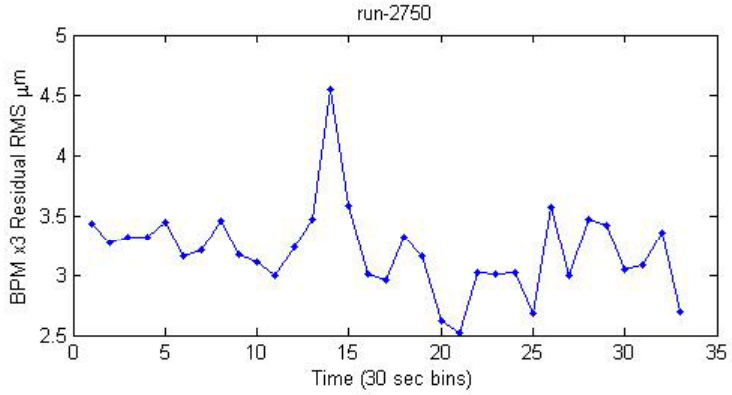


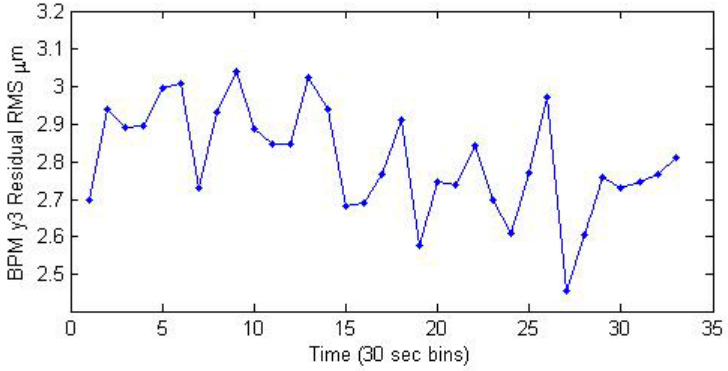


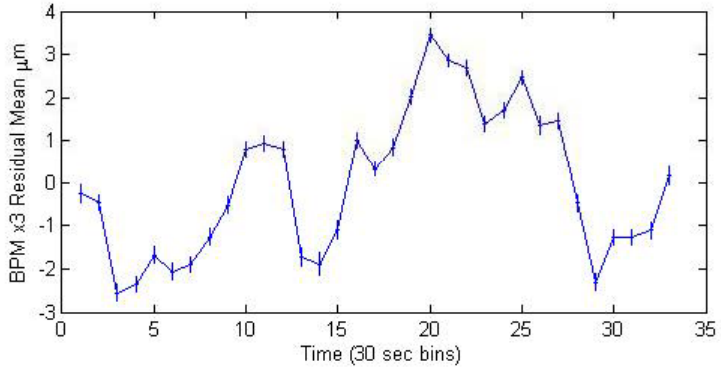
BPM #3 (ILC Prototype S-Band BPM)

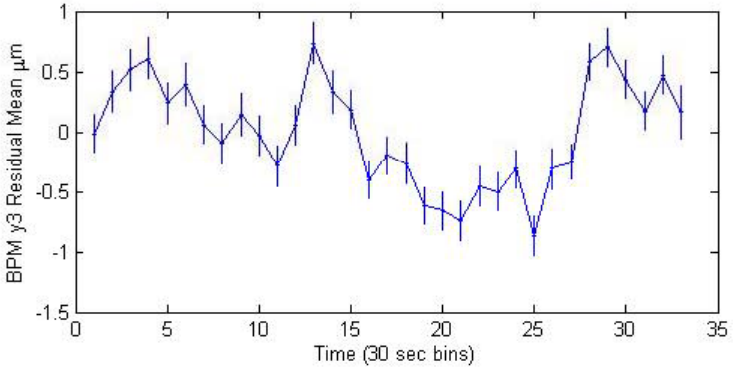


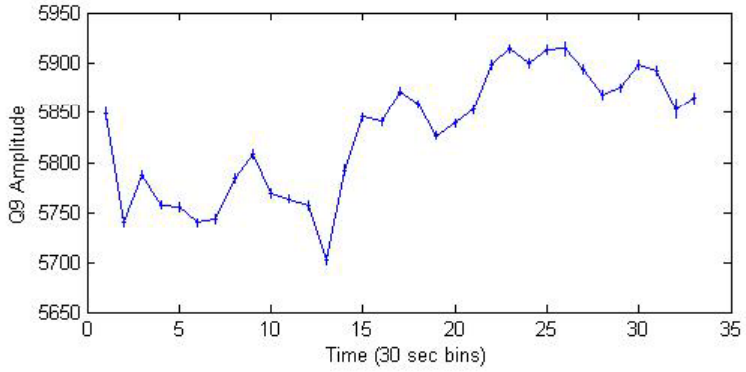
BPM #3 (ILC Prototype S-Band BPM) - Stability

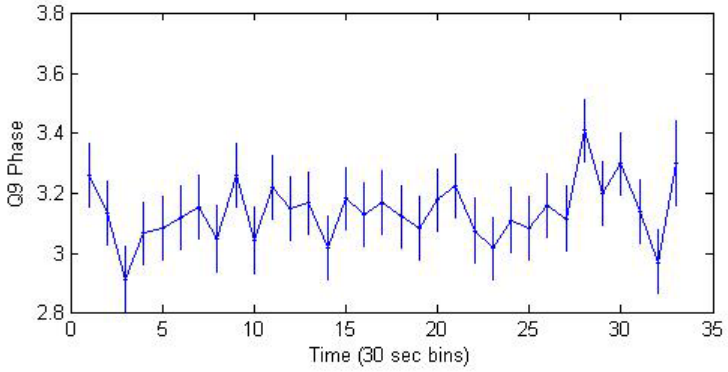






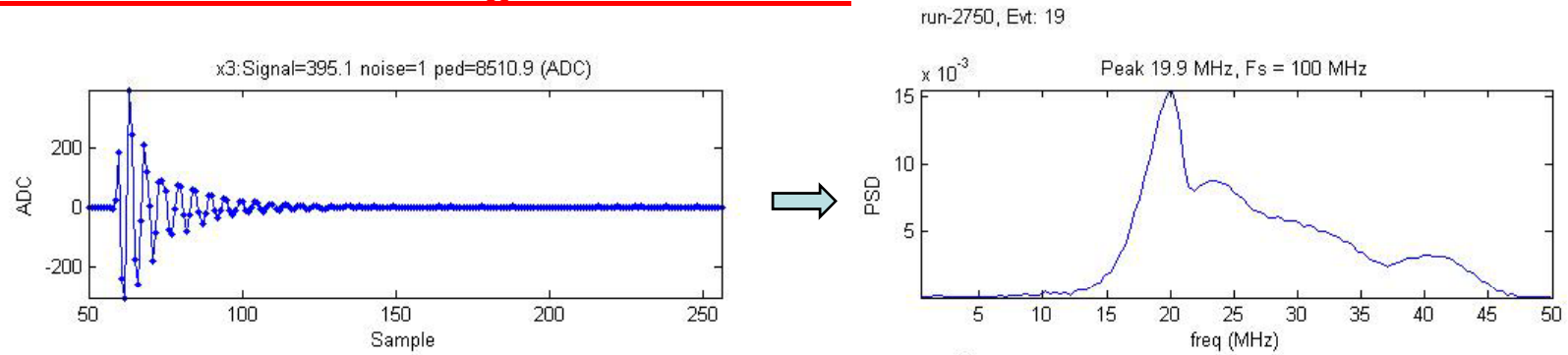




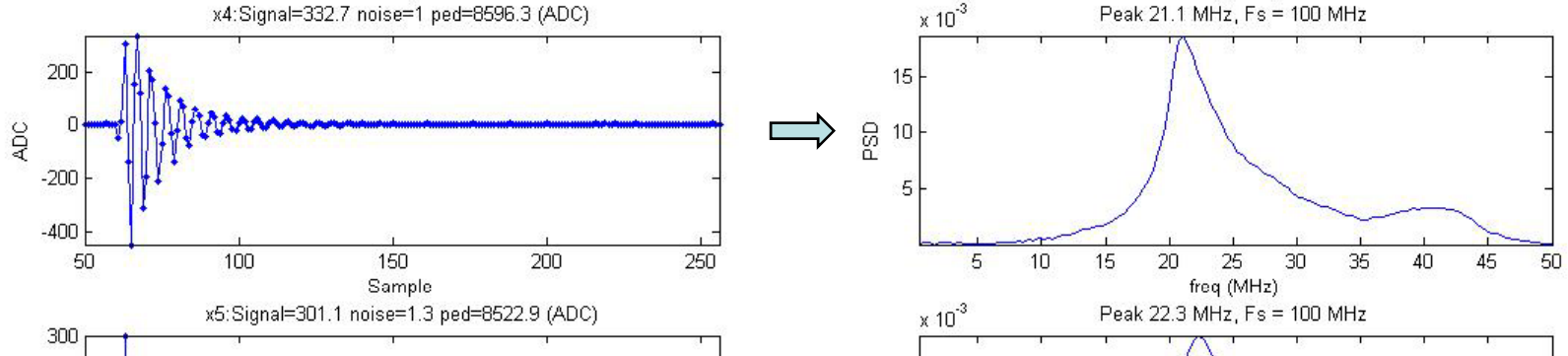


Digitized waveform: raw signal and FFT - X

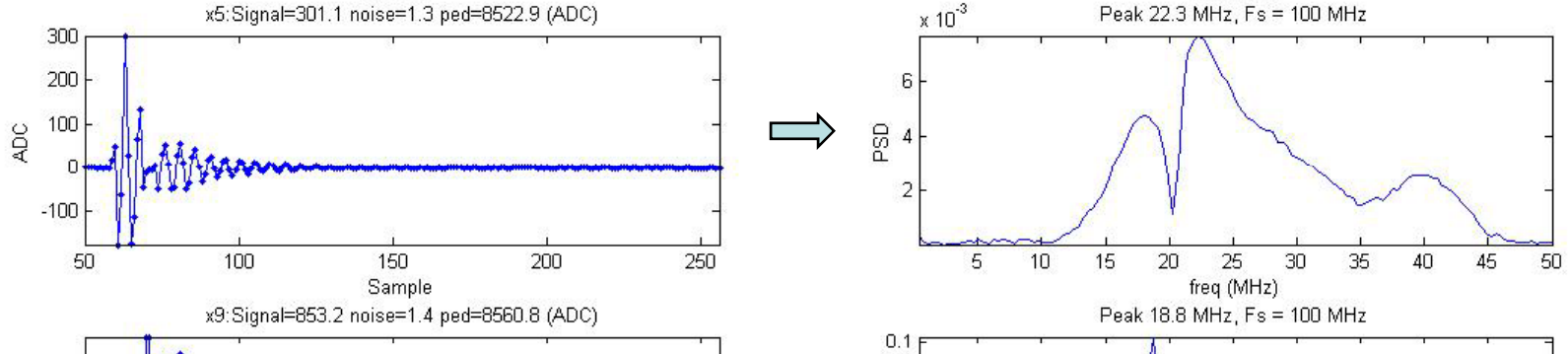
BPM 3x



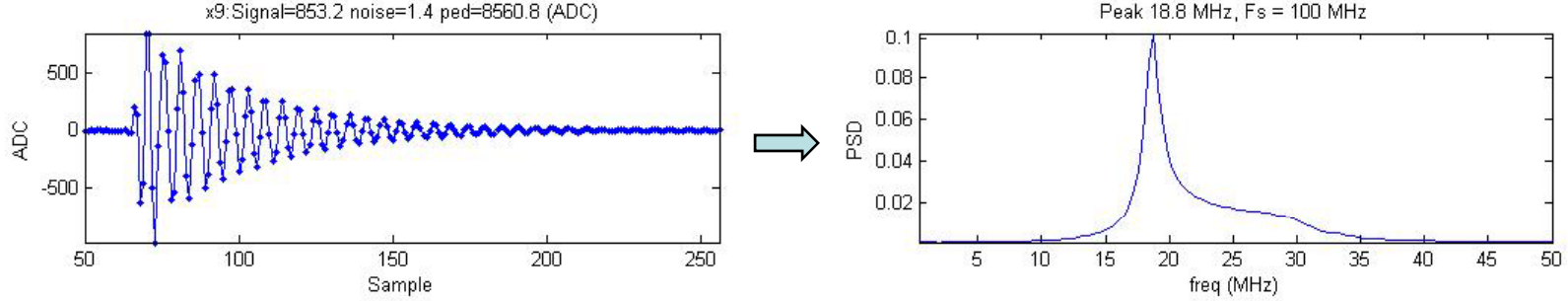
BPM 4x



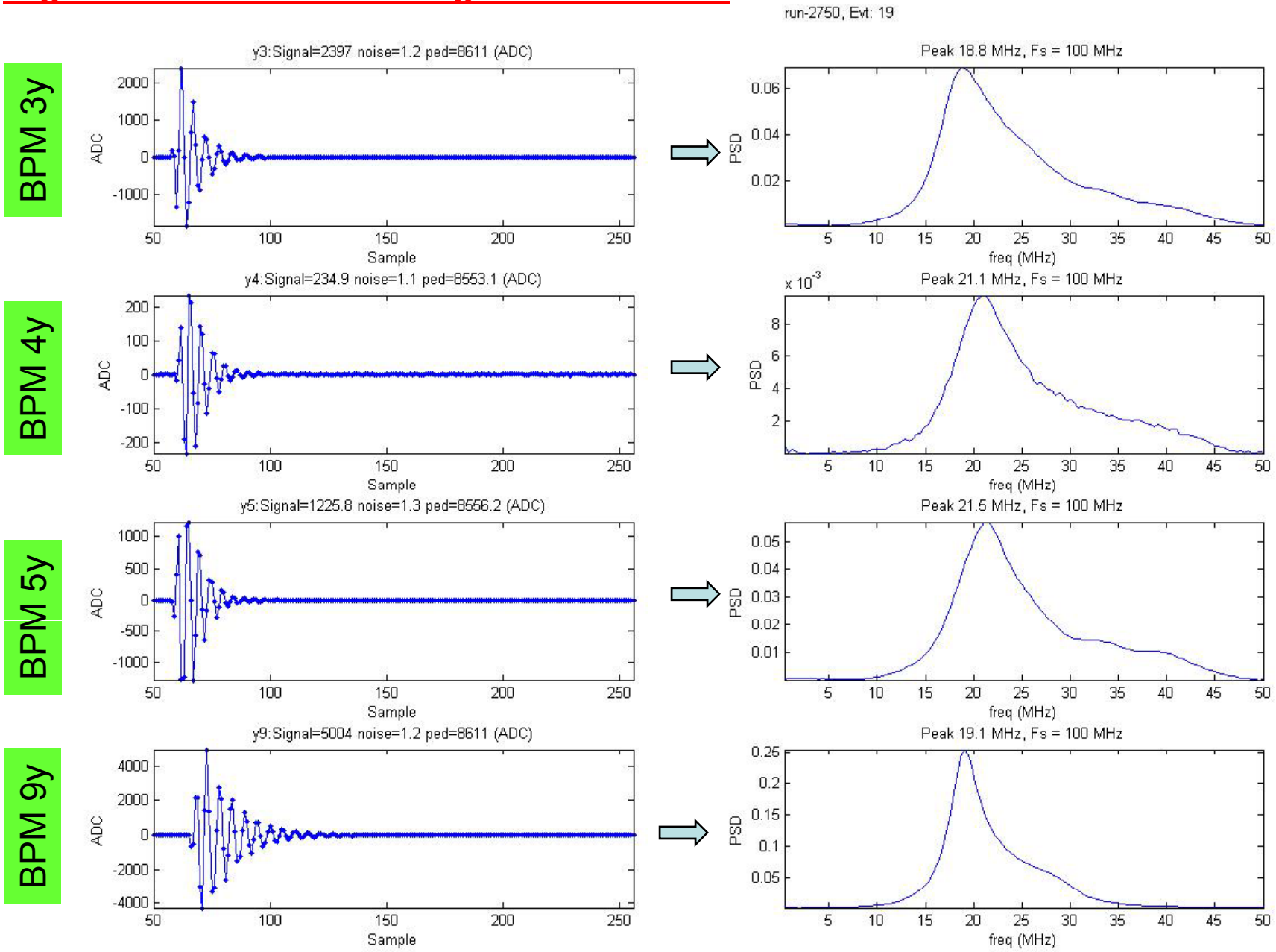
BPM 5x



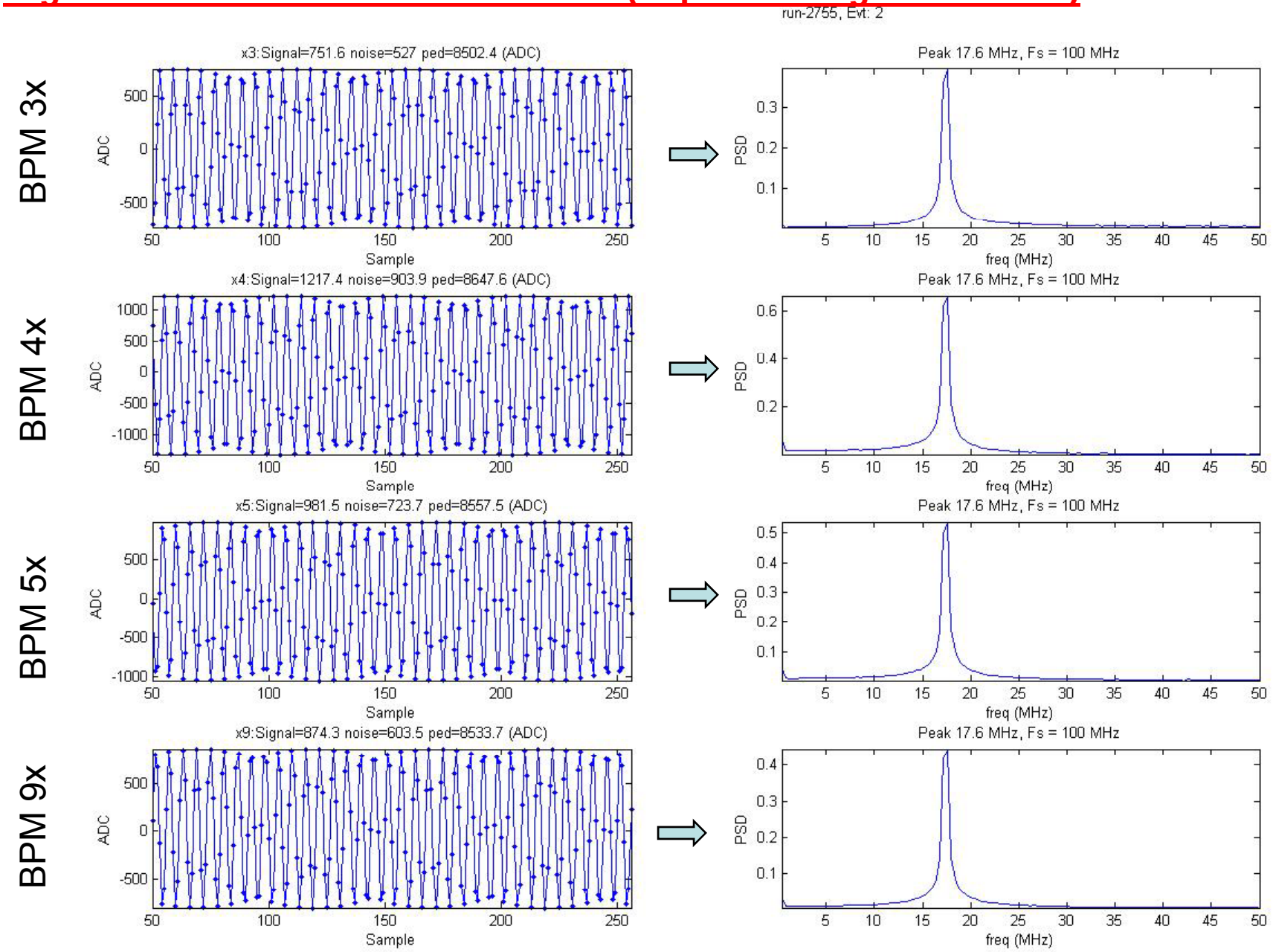
BPM 9x



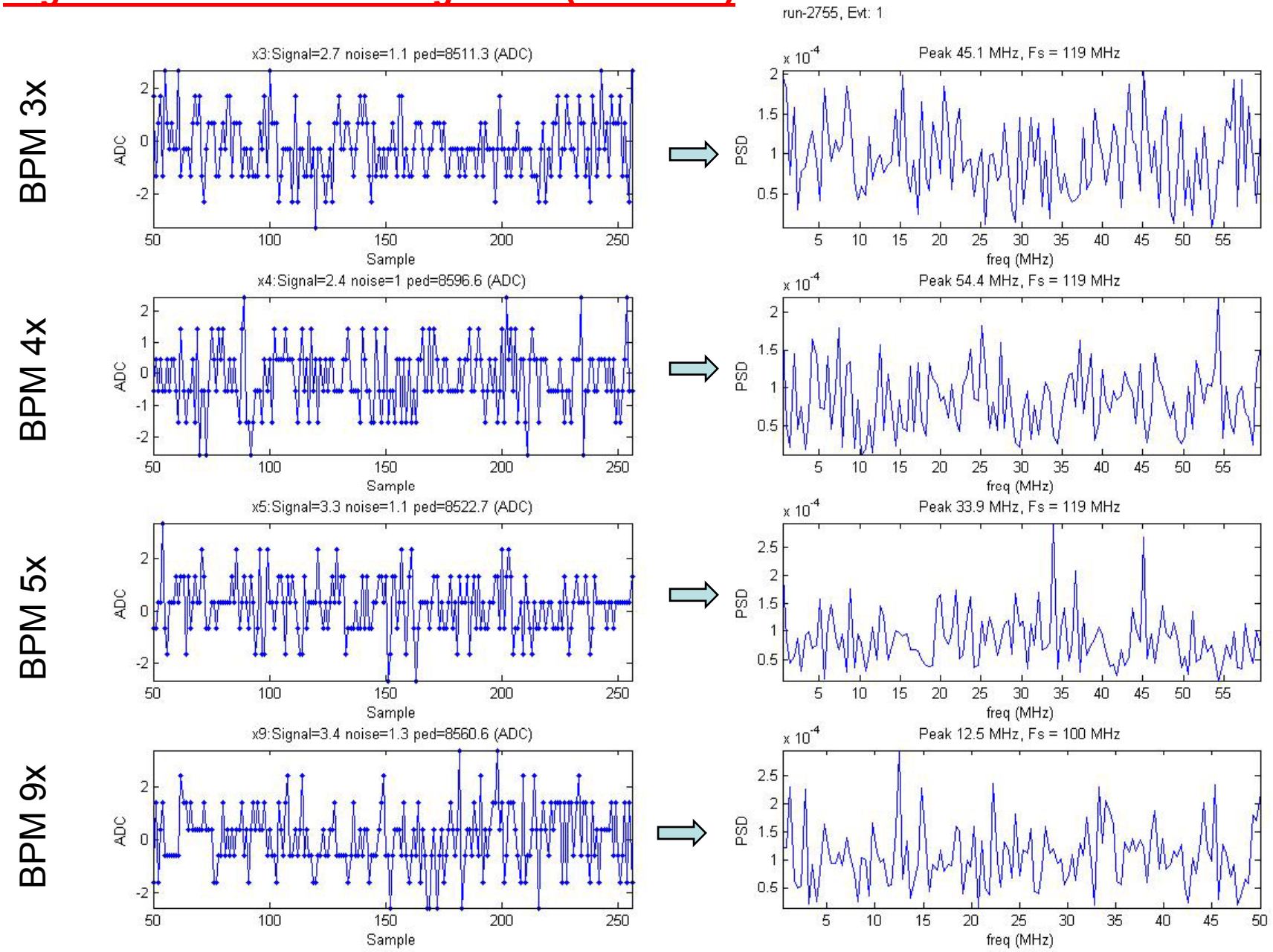
Digitized waveform: raw signal and FFT - Y



Digitized waveform: calibration tone (at processing electronics)



Digitized waveform: background (no beam)



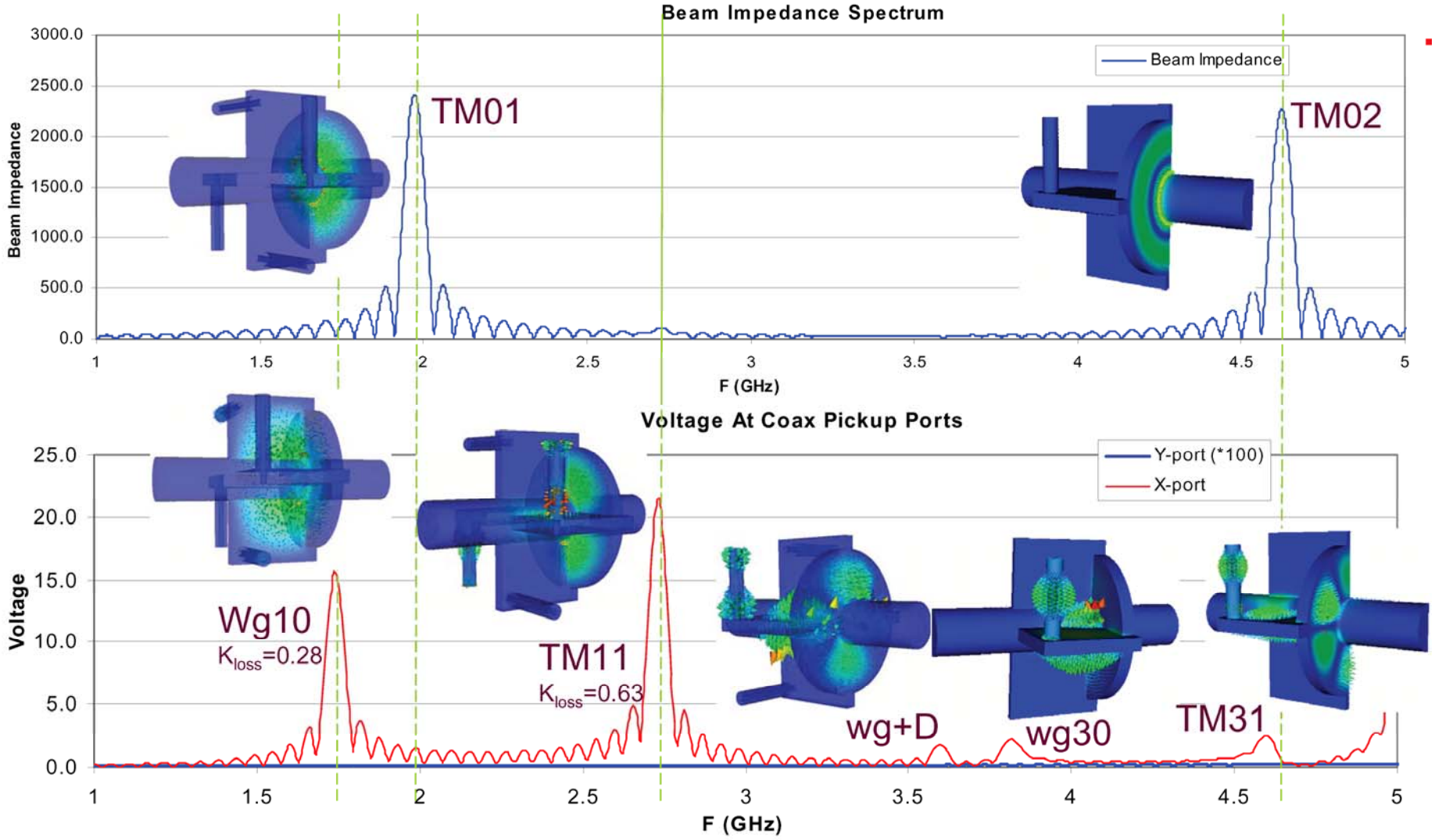
Comparison with Expected Performance

- BPM properties determined from full 3D simulation of design cavity (Z. Li)

- Use BPM parameters (mode frequencies, loss factors, etc.) as input to simple simulation to understand systematics

(From Zenghai Li)

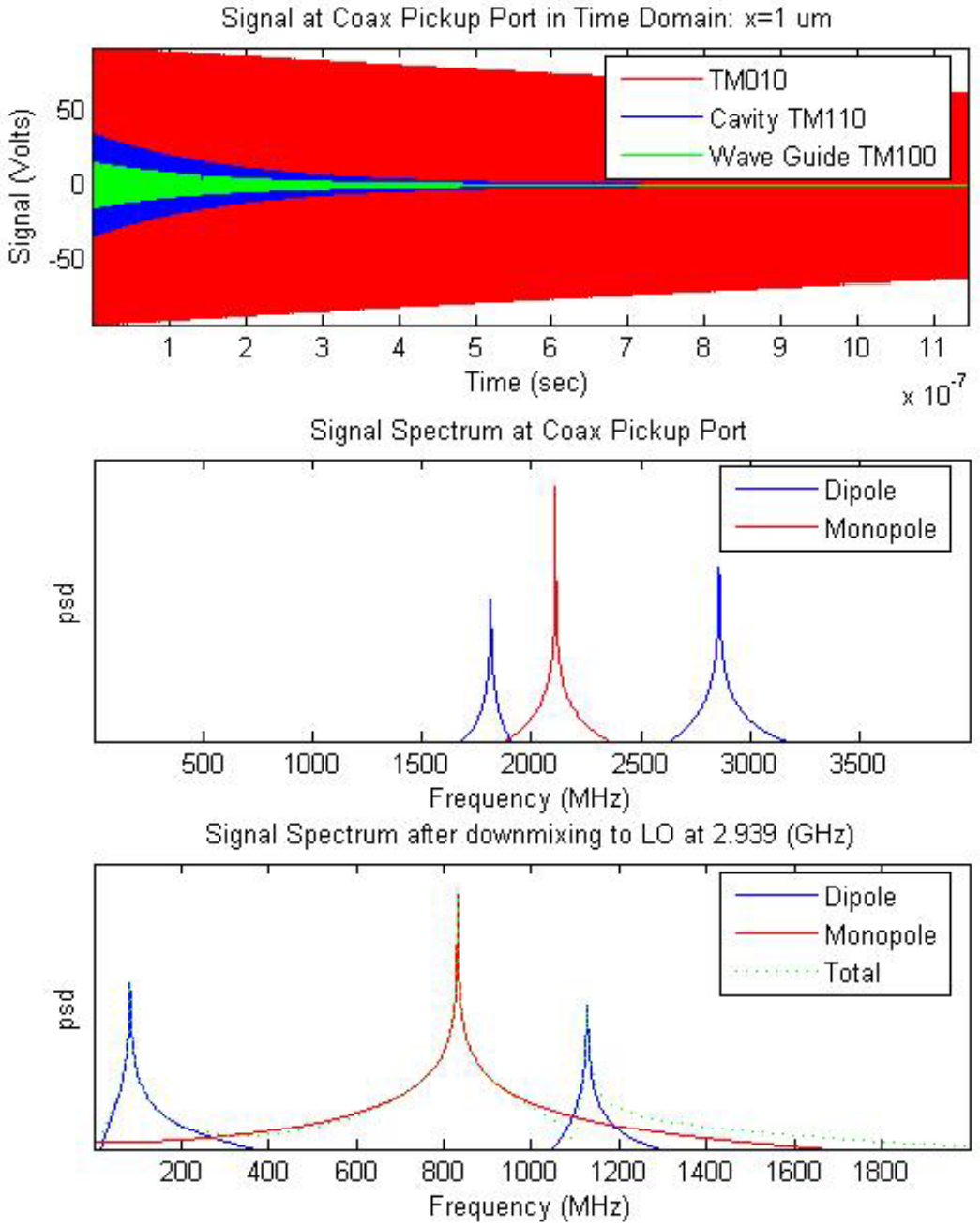
Beam Impedance And Pickup Spectrum In Detail



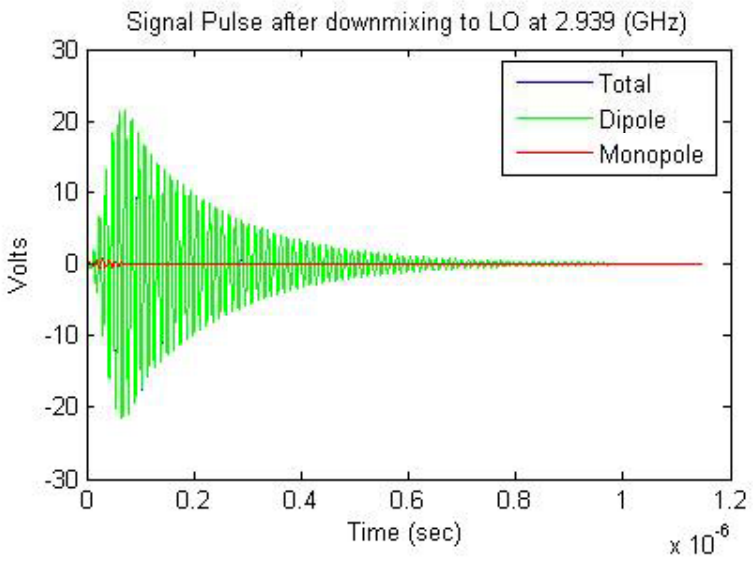
Simple simulation:

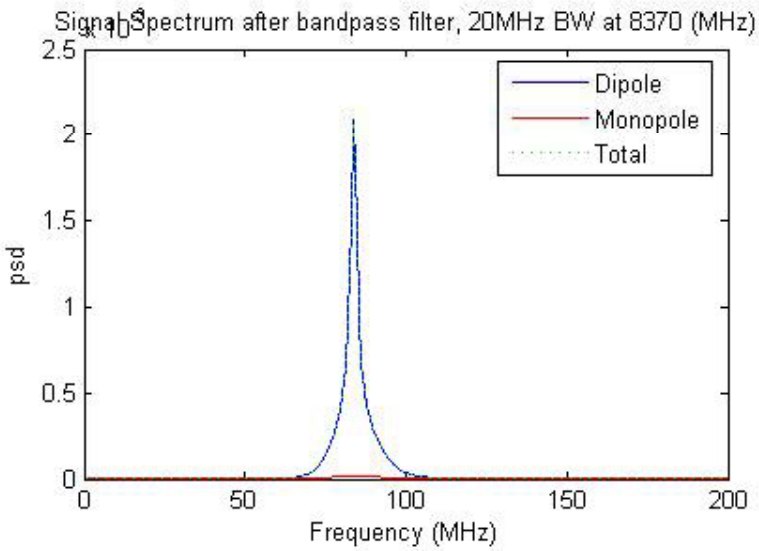
-Dipole and monopole modes
-Apply signal processing
-Apply digitization processing

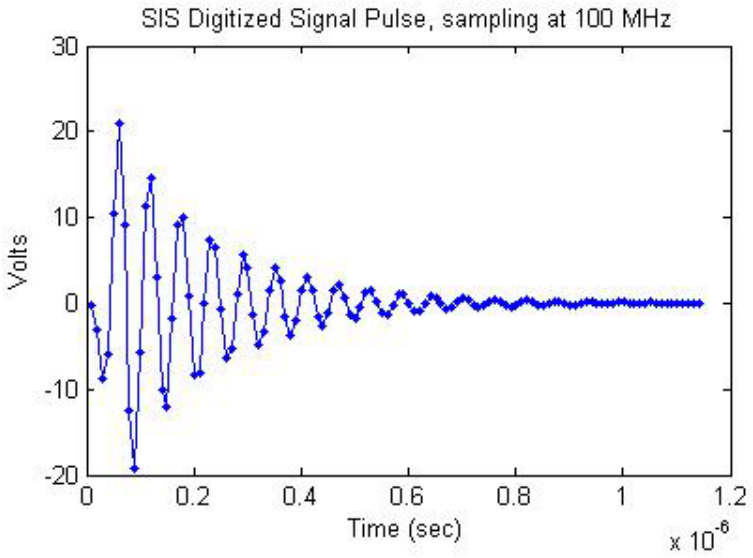
-Add additional effects:
- monopole leakage?
- sensitivity of DDC algorithm to phase shifts, noise, etc..?

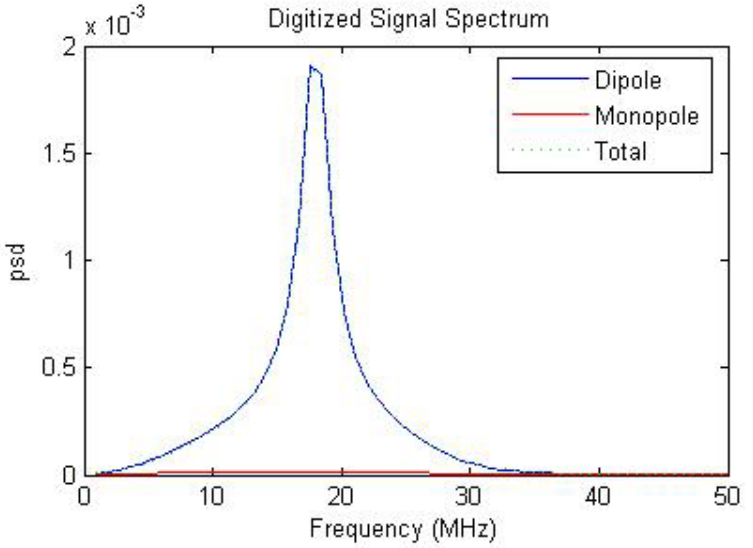


Simple simulation: pulse shape and FFT (downmixing + digitization sampling)









Suumary and Outlook

- Results for ILC BPM encouraging so far:
  - Demonstrated sub-micron resolution
  - Typical long-term (hour) stability ~ 1 micron
  - Mover calibration appears stable

- Further work needed:
  - Source of mechanical vibration?
  - Why resolution worst than expected?
  - Multiple modes in frequency spectrum?
  - Operational issues: optimize calibration procedure