Monochromator Vibration Considerations

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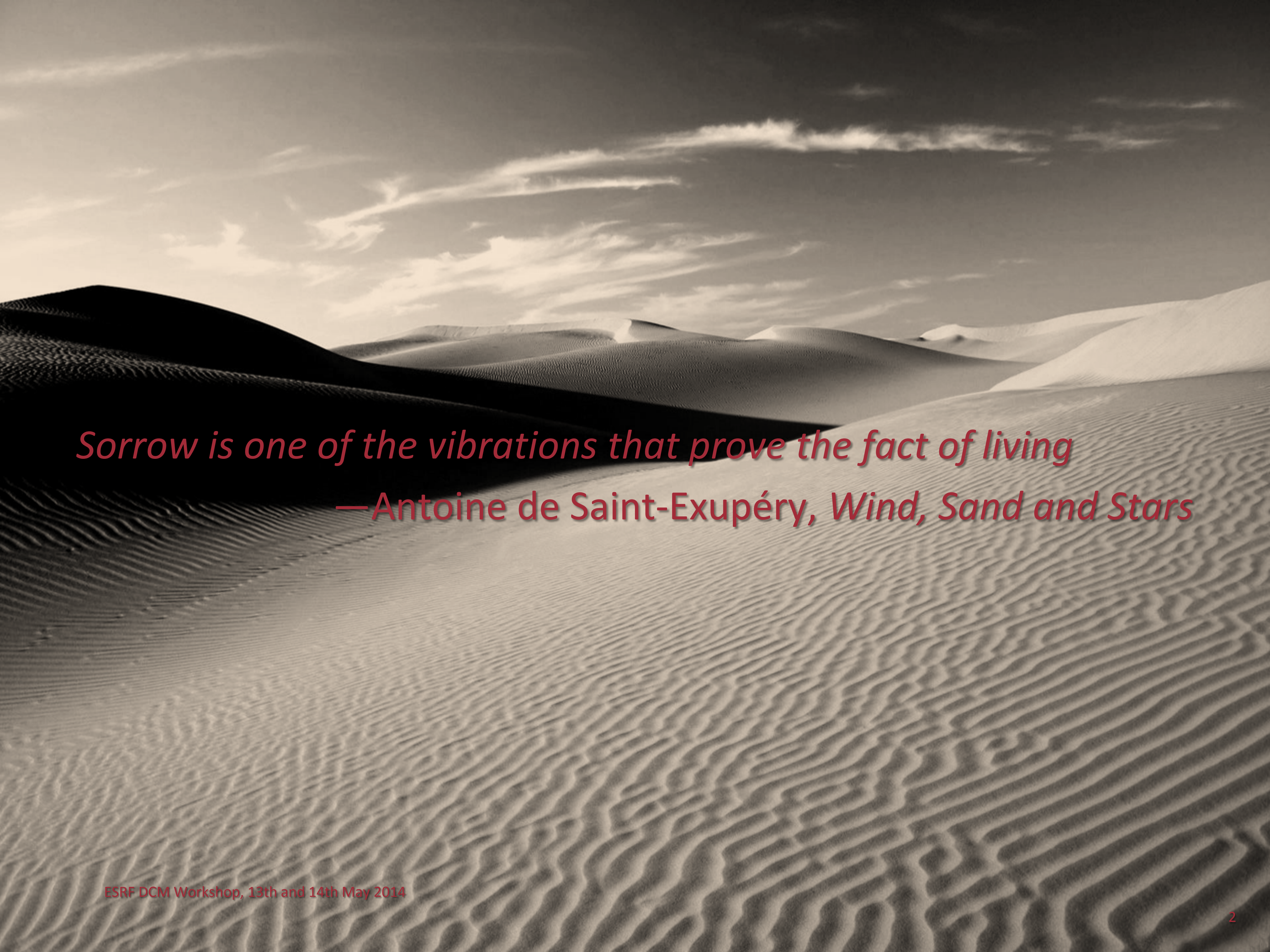


Sorrow is one of the vibrations that prove the fact of living

—Antoine de Saint-Exupéry, *Wind, Sand and Stars*

Vibrations are one of the sorrows of the synchrotron

—Anonymous, *02:00 at a beamline somewhere*

Outline

- Background: what, why, and how
- Case study 1: S07 BM Double Multilayer Monochromator (DMM)
- Case study 2: S02 ID DMM
- Summary of our method
- Conclusions

Background

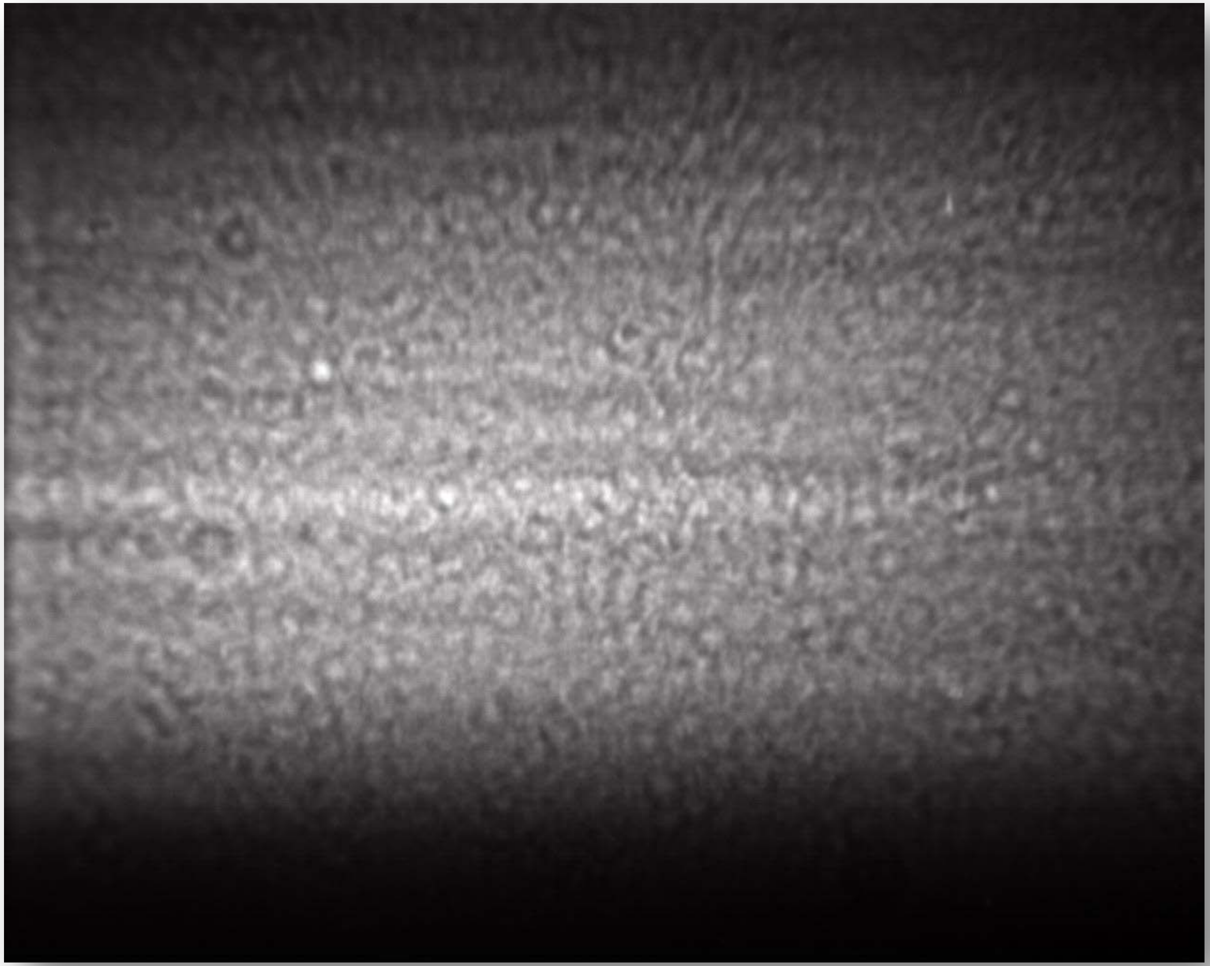
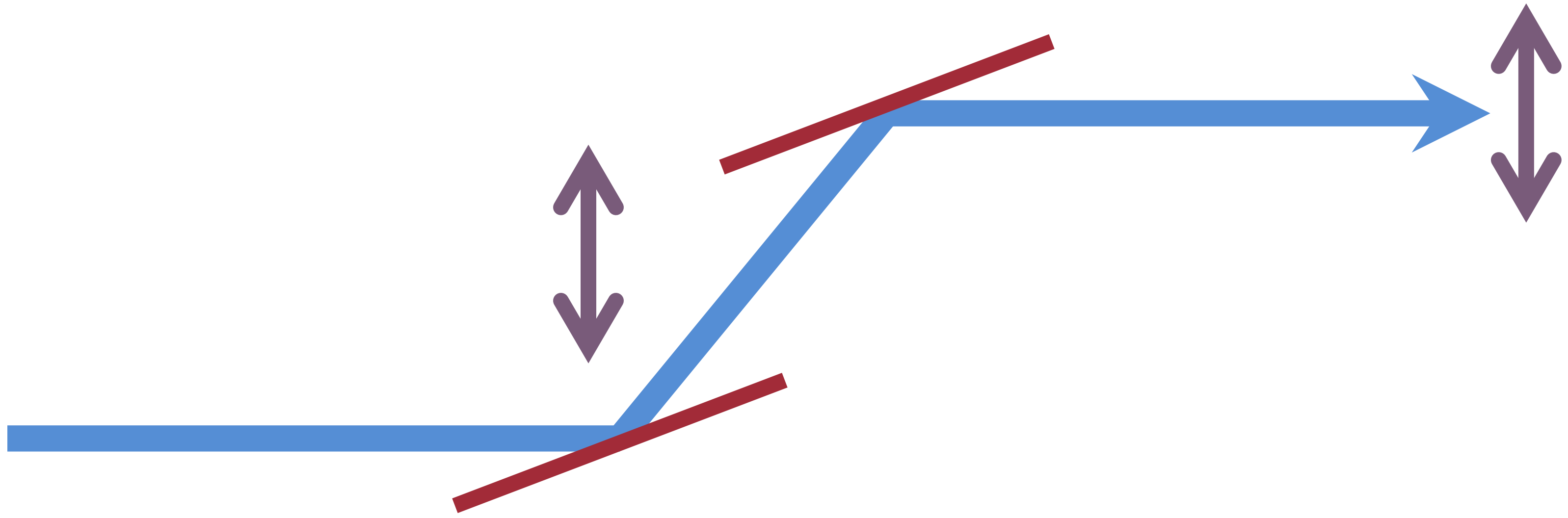


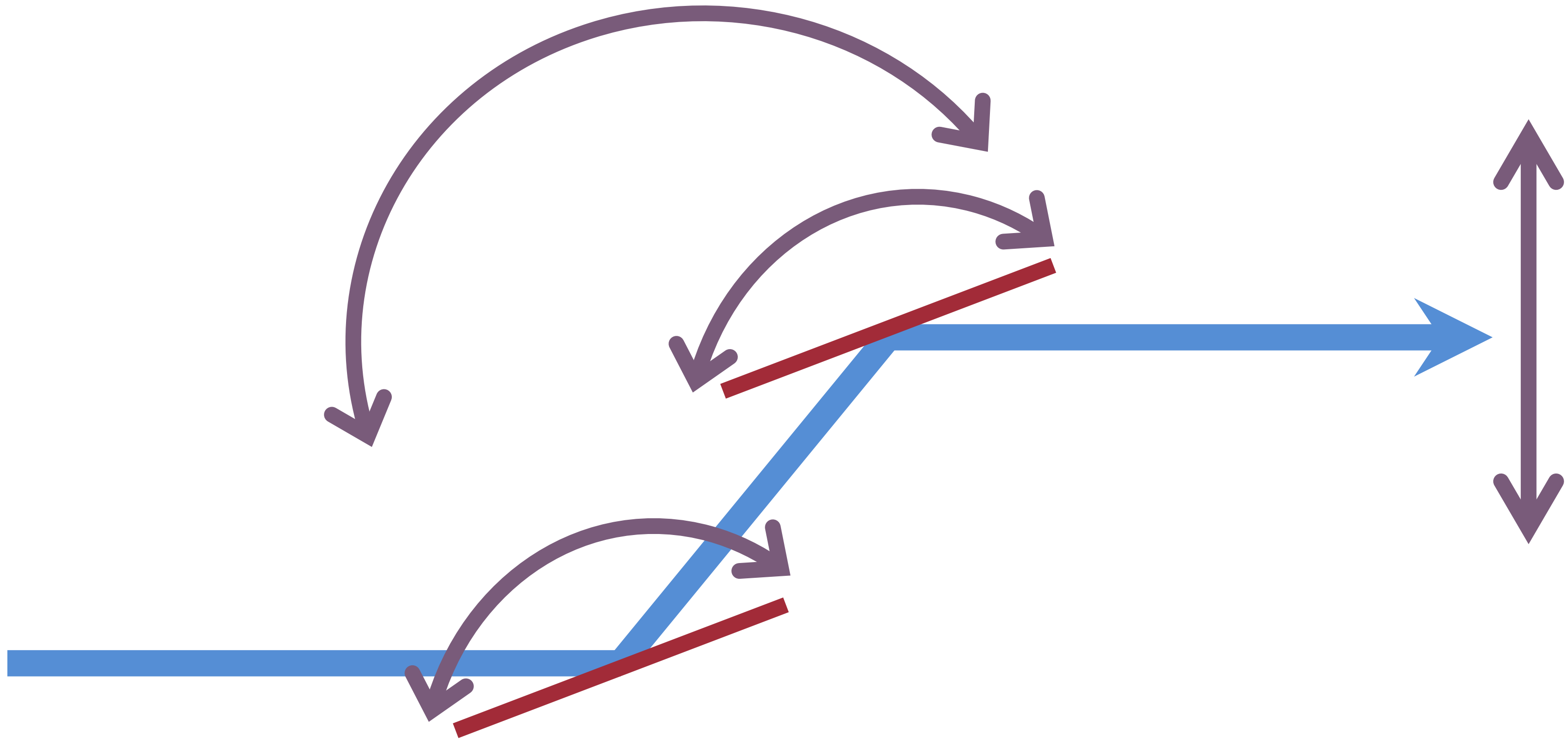
Image of beam from S02 ID Double Multilayer Monochromator

Background: Crystal perturbations and beam motion



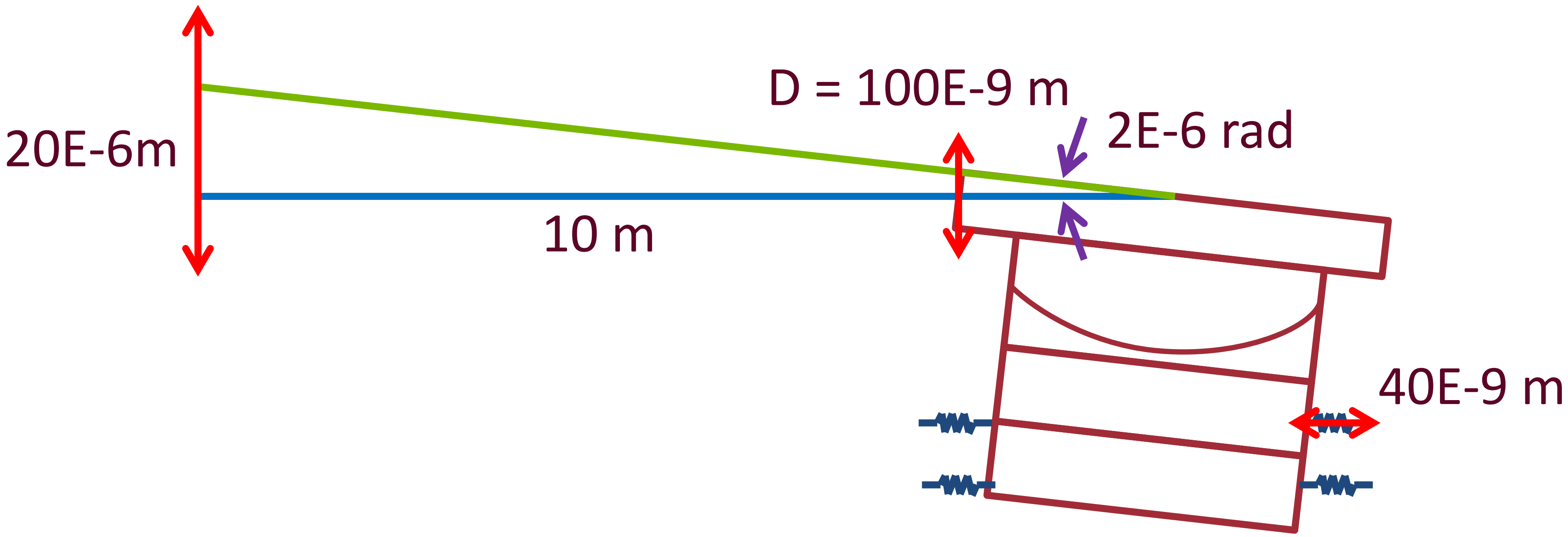
Small translations at mono = small beam motion at endstation

Background: Crystal perturbations and beam motion

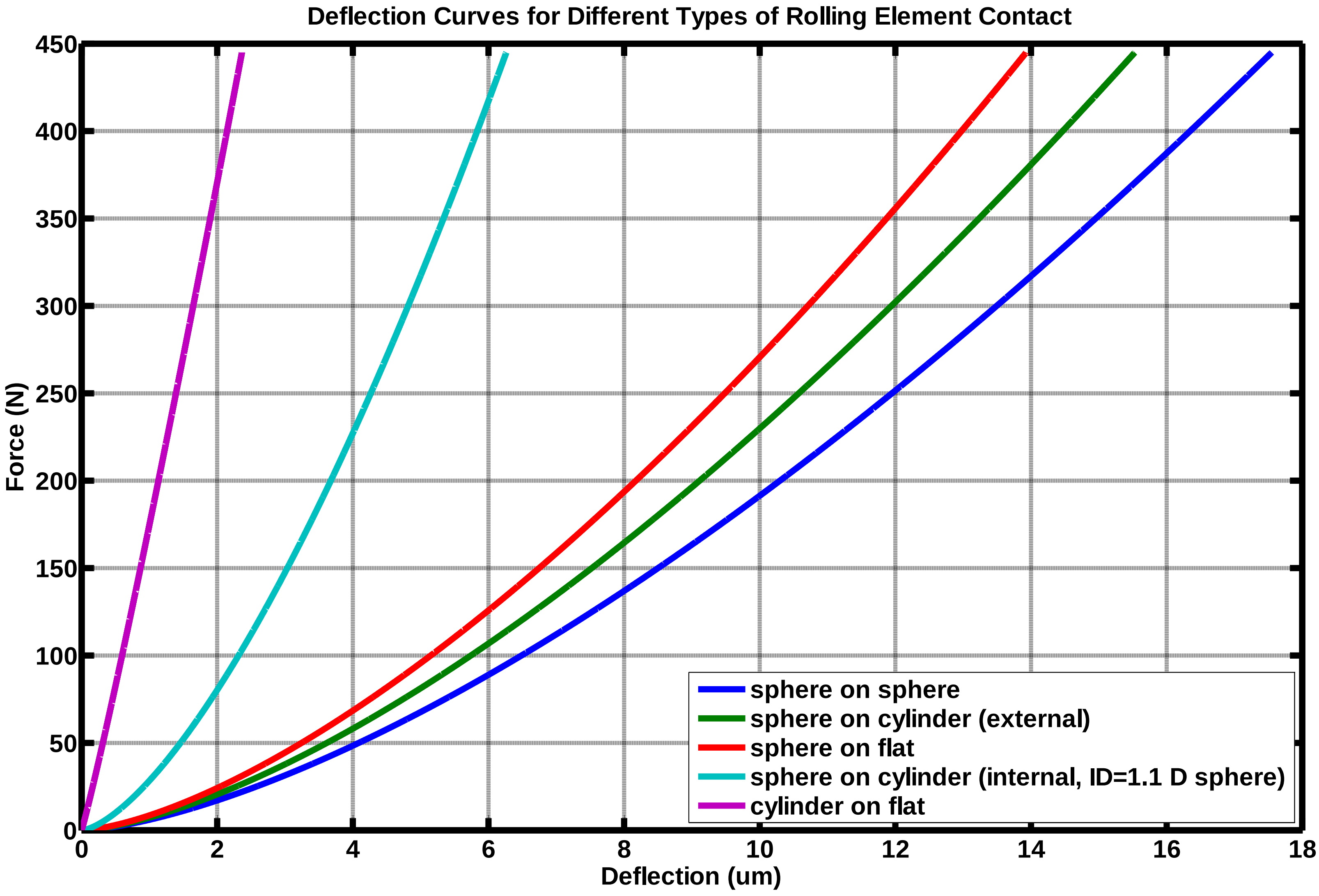


Small rotations at mono = large(r) beam motion at endstation

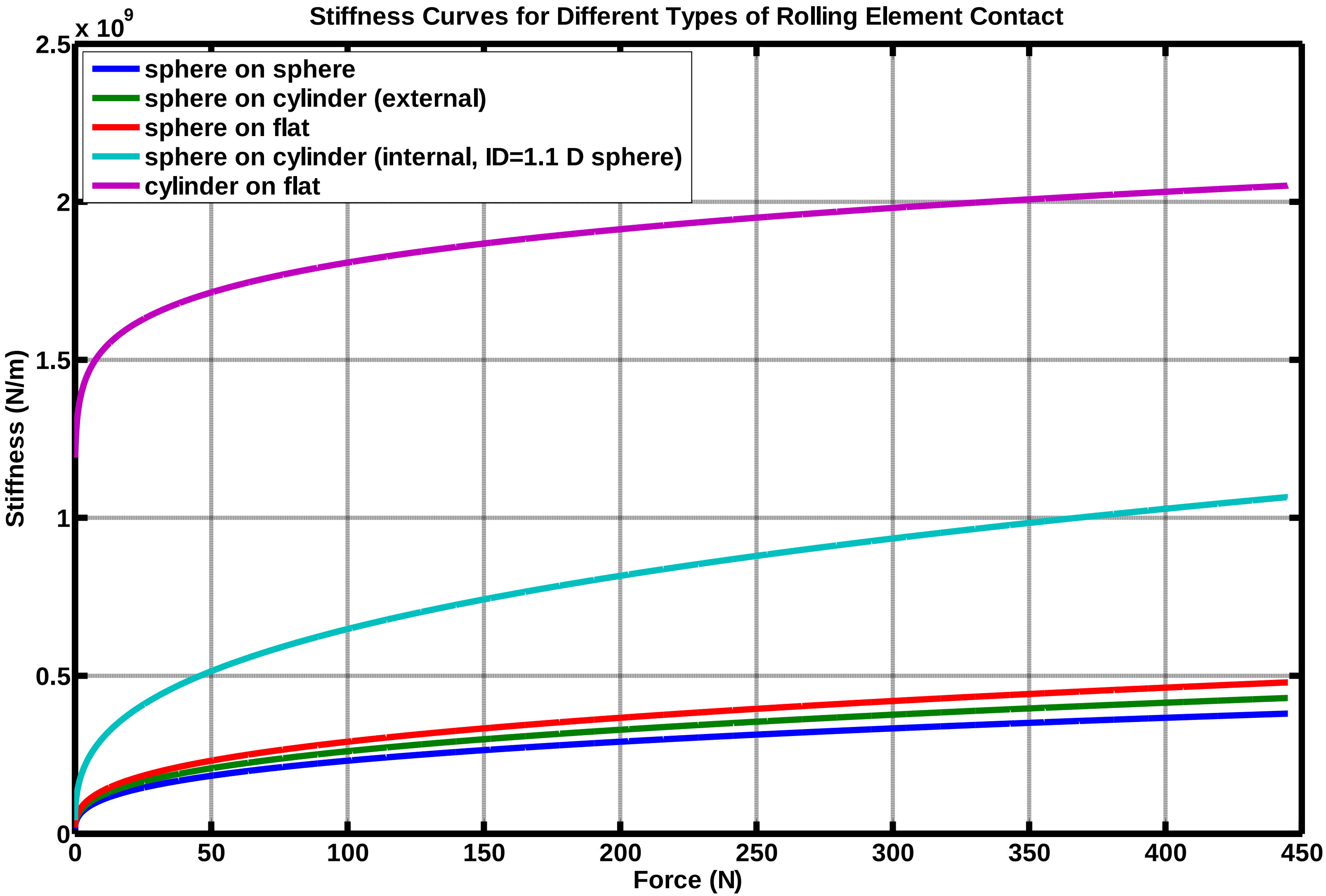
Background: A little (motion) goes a long way



Background: Why might an instrument be susceptible?



Background: Be rigid in your thinking



Background: Tools of the trade

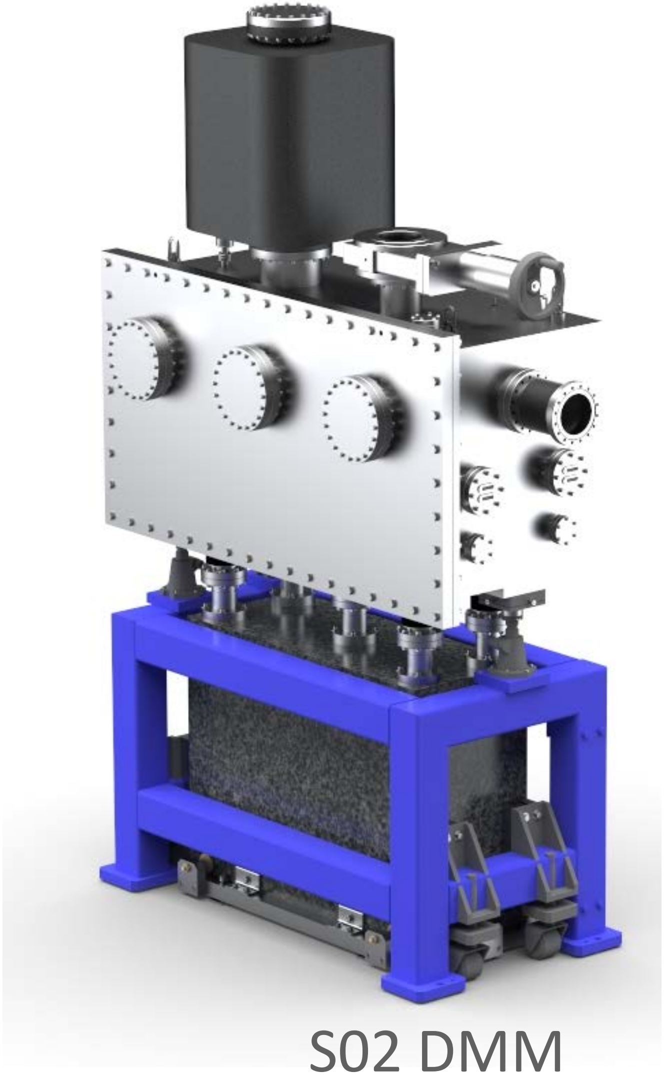
- Data Acquisition – Data Physics Abacus
- Accelerometers
  - PCB 393B31, single axis, 635 grams, 1 nm/√Hz @ 7Hz
  - PCB 393B05, single axis, 50 grams, 10 nm/√Hz @ 7Hz
  - PCB 356B18, triaxial, 25 grams

- Impact hammers
  - PCB 086E80, 4.8 grams
  - B&K 8202, 402 grams
  - PCB 086D50, 5.5 kilograms

- Polytec OFV-534 Laser Doppler Vibrometer
- Modal analysis can be used to estimate stiffness, and mode shapes (as opposed to operating shapes)

Background: Tell me what's wrong but don't open it up

- 1st check ambient levels
- Measure supports/outside tank
- Characterize beam motion
- Subsequently open instrument to make measurements



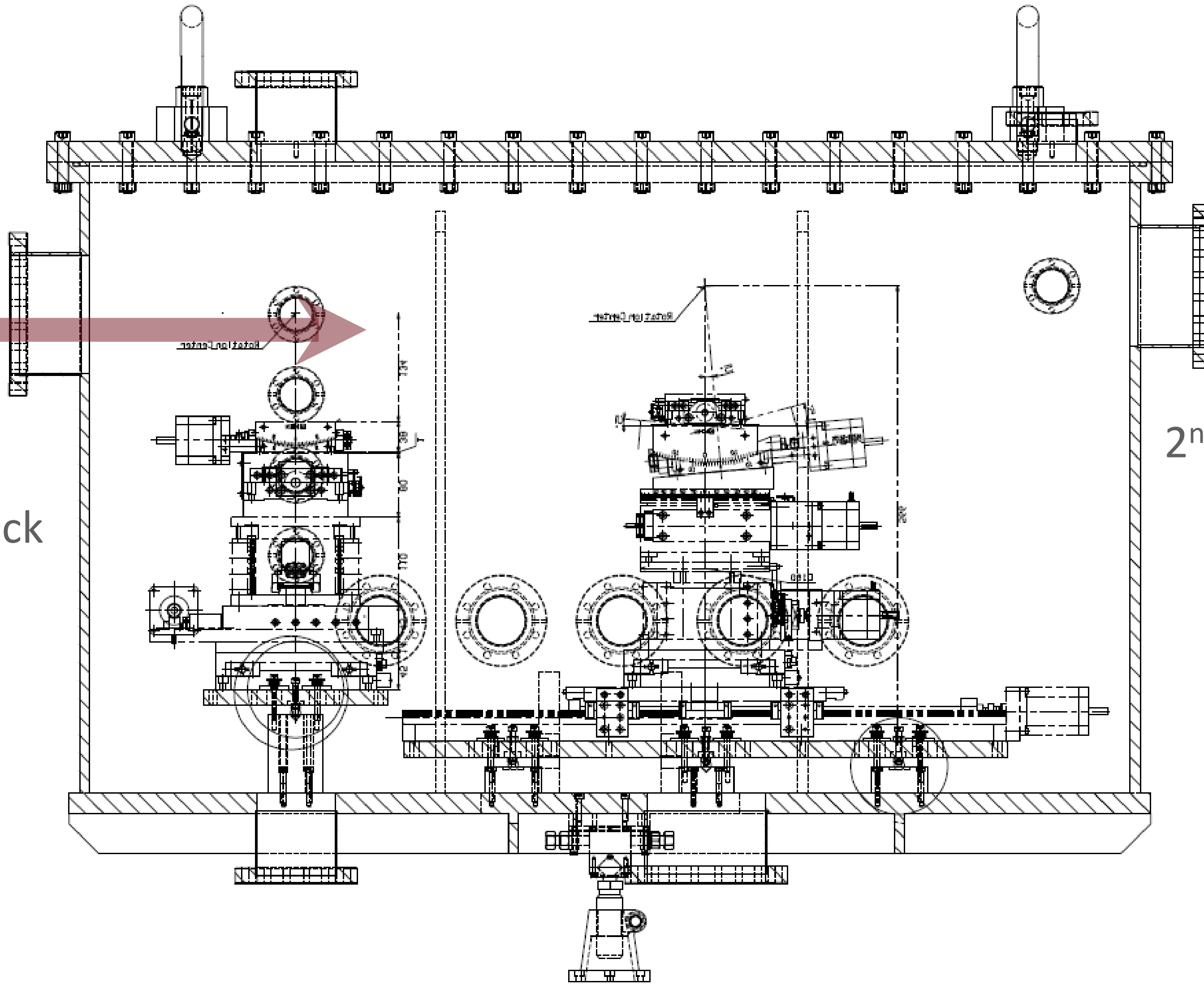
S02 DMM

Case Study 1: Sector 7 BM Double Multilayer Mono

Y

Z

X-ray beam



1st stage stack

- $\chi 1$
- $\theta 1$
- Y1
- X1

2nd stage stack

- $\chi 2$
- $\theta 2$
- Y2
- X2
- Z2

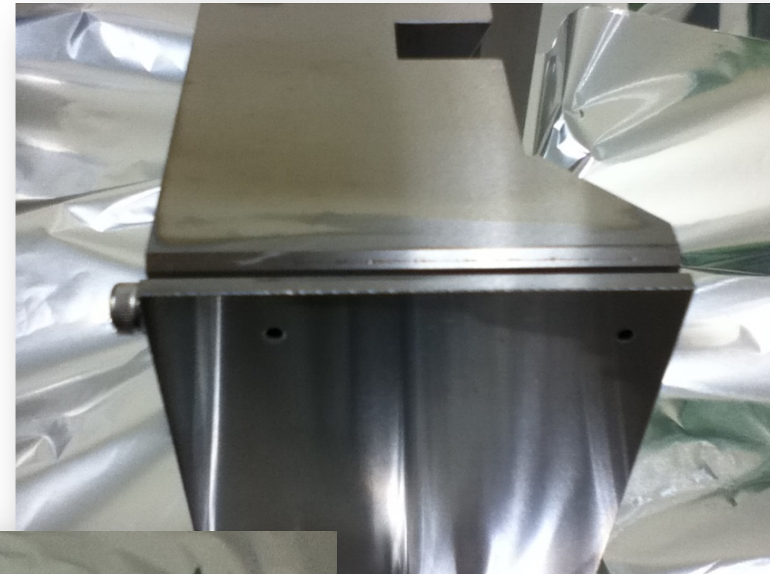
Case Study 1: Timeline

- October 2008 – Installation
- May 2009 – first signs of vibration issues, user contact
- August 2010 – initial investigation
- October 2010 – internal measurements, broken parts
- September 2011 – additional measurements
- November 2012 – beam motion
- January 2013 – more internal measurements

Case Study 1: Wandering in the desert

- Initial beam characterization was misleading
  - Camera frame rate was insufficient
  - Operational conditions were be different than conditions when imaging beam vibration were different than when measuring vibration
  - A roughing pump was connected to an evacuated flight path in the next hutch
- A number of “mirages”
  - Missing fasteners
  - Broken/incorrect baseplate mounting
  - Damaged vertical stage, fretting
- Cycle times between measurements were long
- Access to internals was limited

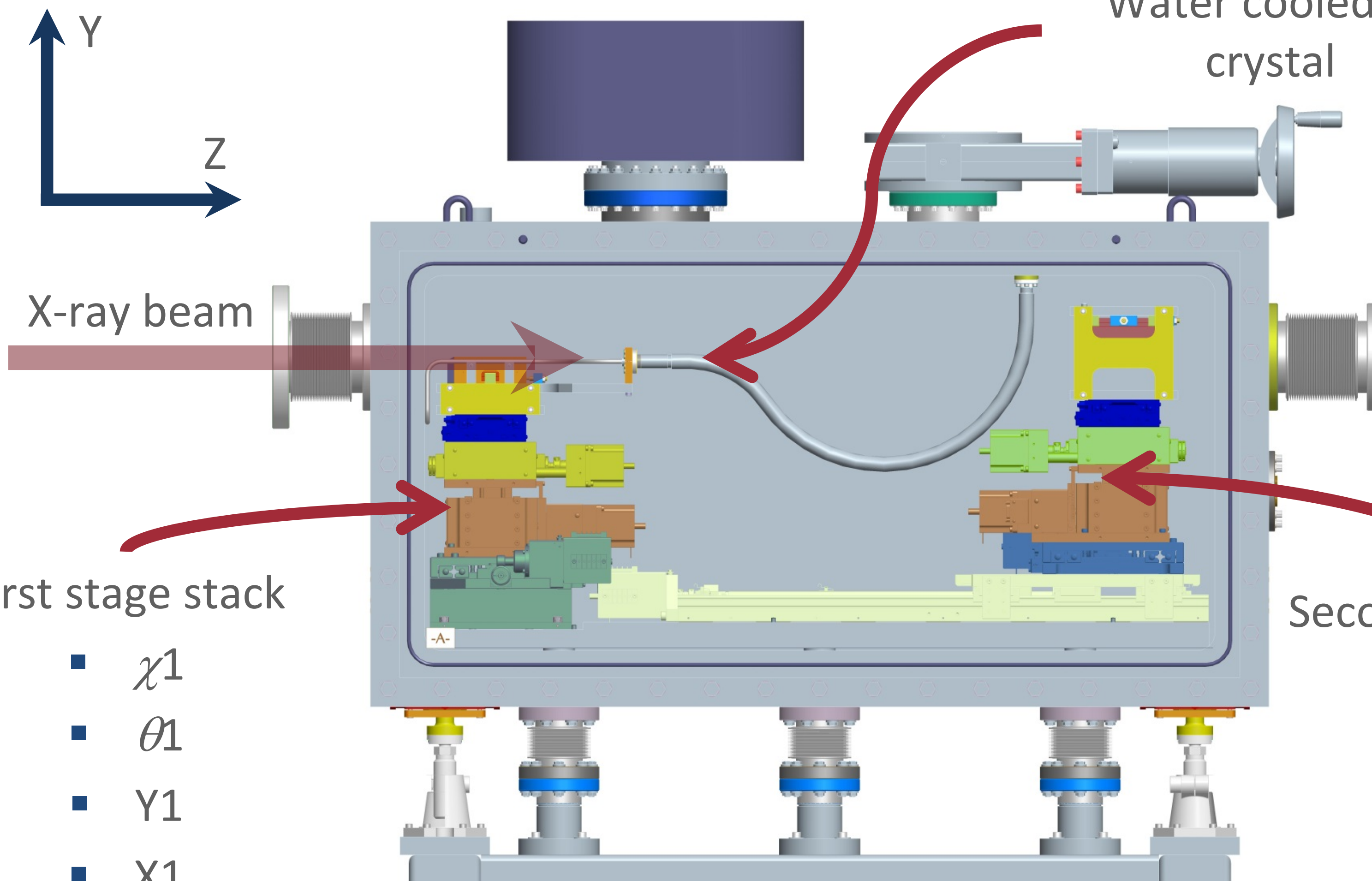
Case Study 1: Mirages



Case Study 1: Oasis on the horizon?

- Lack of good beam=>mechanics correlation caused lots of time to be spent
- Real problems were identified
- However, they were not problems that contributed greatly to beam motion
- Subsequent beam measurements, vibration measurements, and modal analysis located problems
  - 20 Hz peak associated with tank support (also close to 1st crystal stack resonance dominated by Y stage)
  - 37 Hz peak associated with 2nd crystal stack Y stage
- Fix: Eventualy replace 2nd crystal Y stage (only enough money for one)

Case Study 2: Sector 2 ID Double Multilayer Mono



First stage stack

- $\chi 1$
- $\theta 1$
- Y1
- X1

Second stage stack

- $\chi 2$
- $\theta 2$
- Y2
- X2
- Z2

Case Study 2: Timeline

January 2013 – Installation

July 2013 – Initial measurements

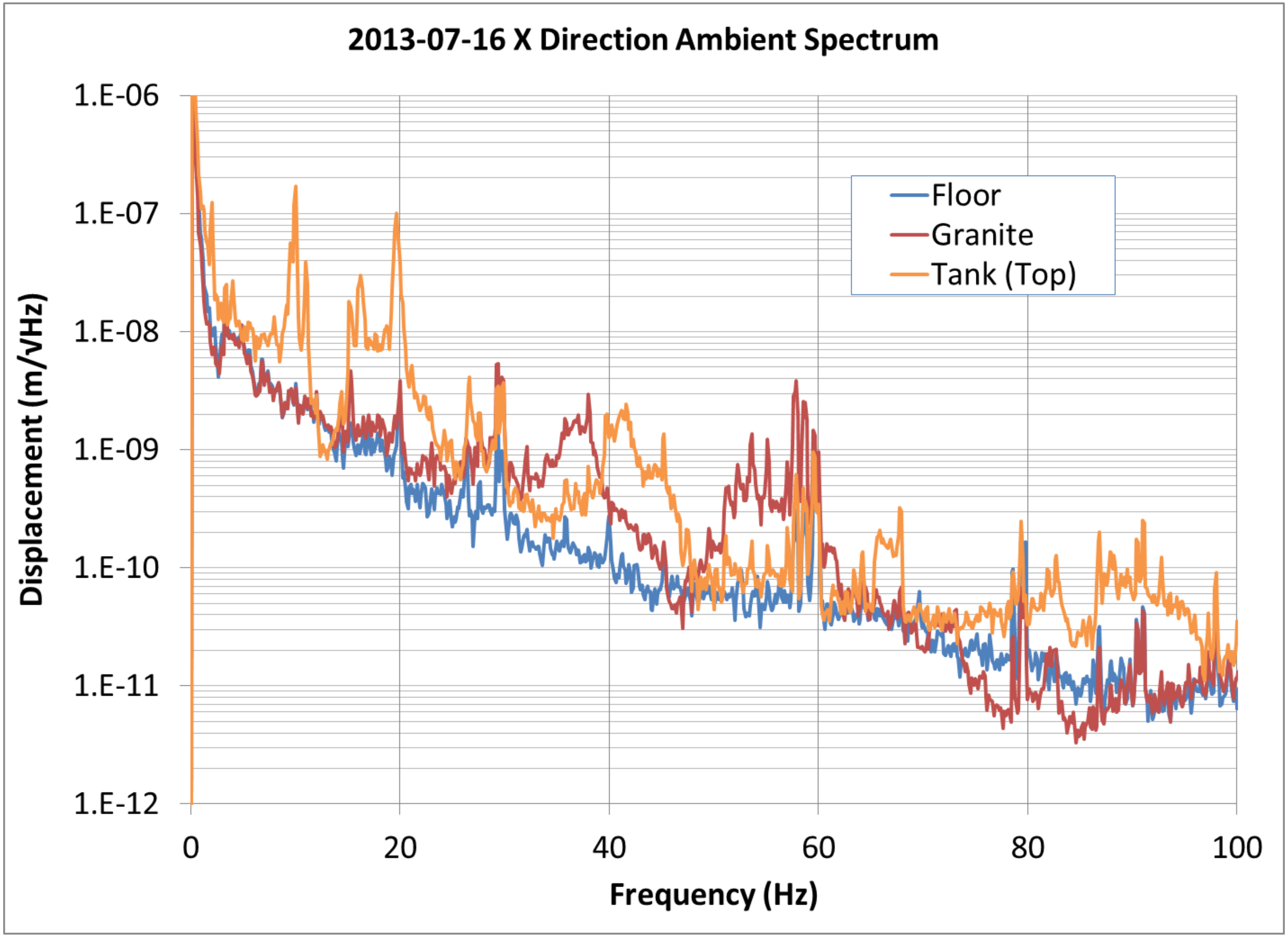
August 2013 – Beam motion

September 2013 – Modal analysis

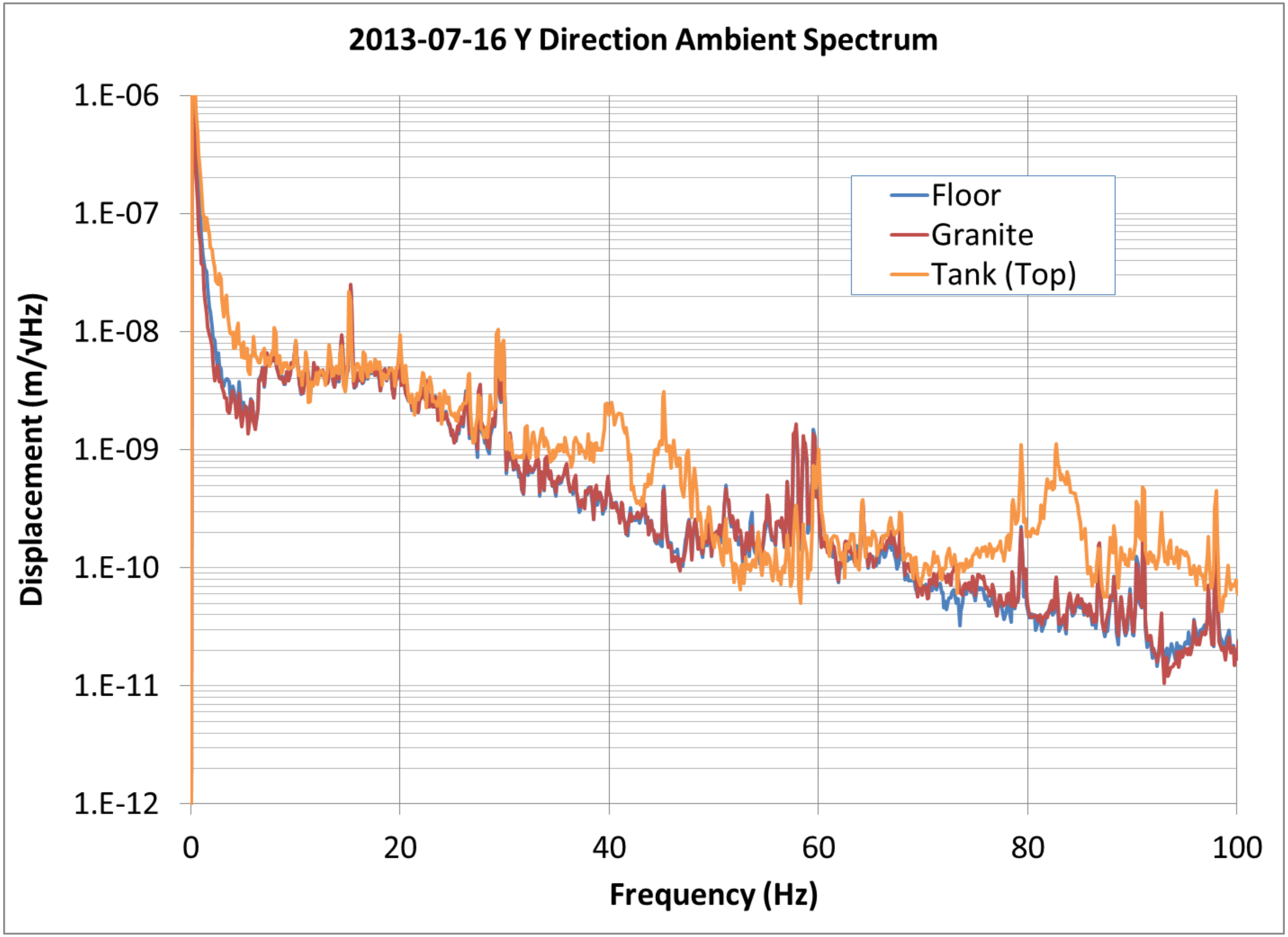
March 2014 – Beam motion measurements (after temporary fix)

May 2014 – Order replacement stages

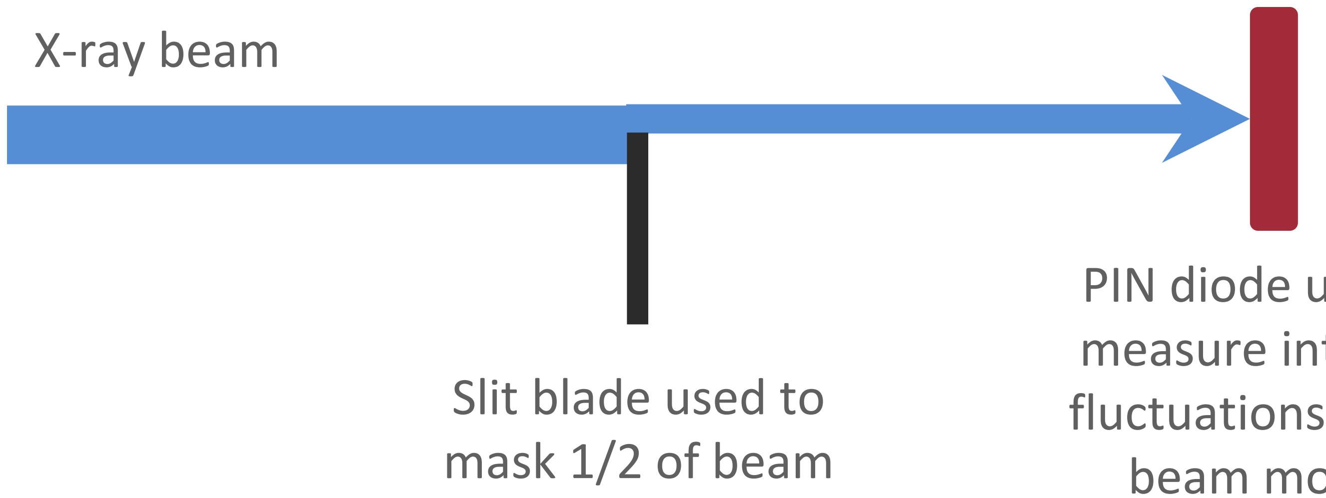
Case Study 2: Transverse direction ambient vibration



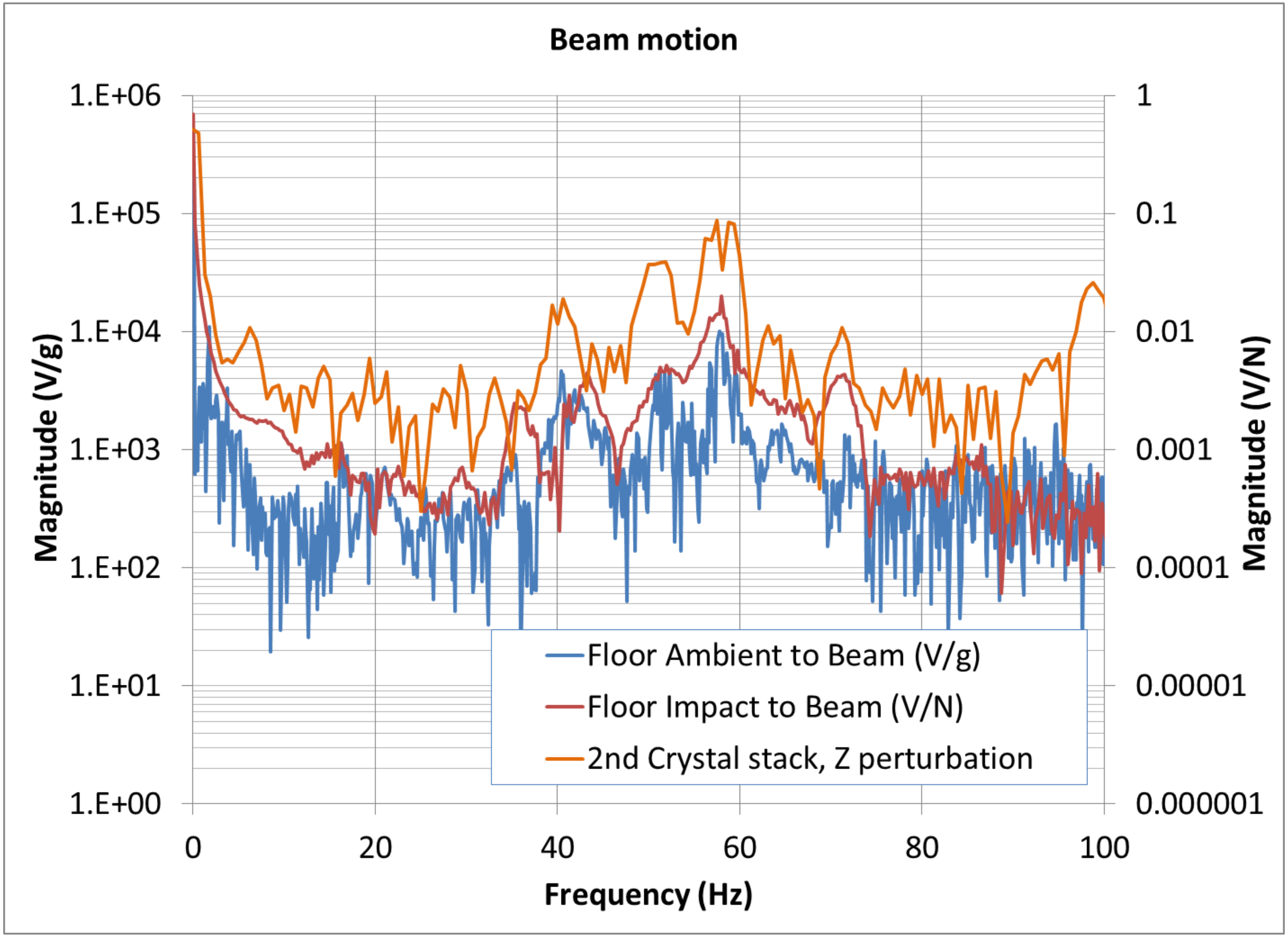
Case Study 2: Vertical direction ambient vibration



Case Study 2: Beam motion measurements

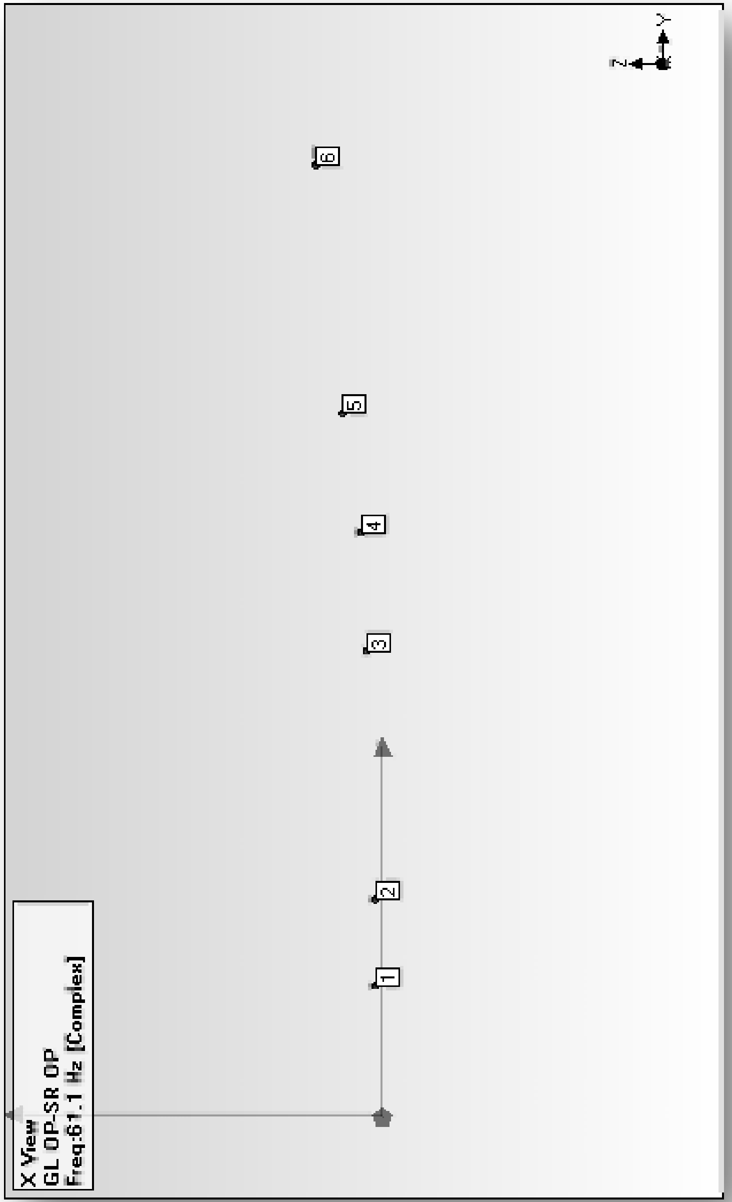


Case Study 2: Beam motion measurements

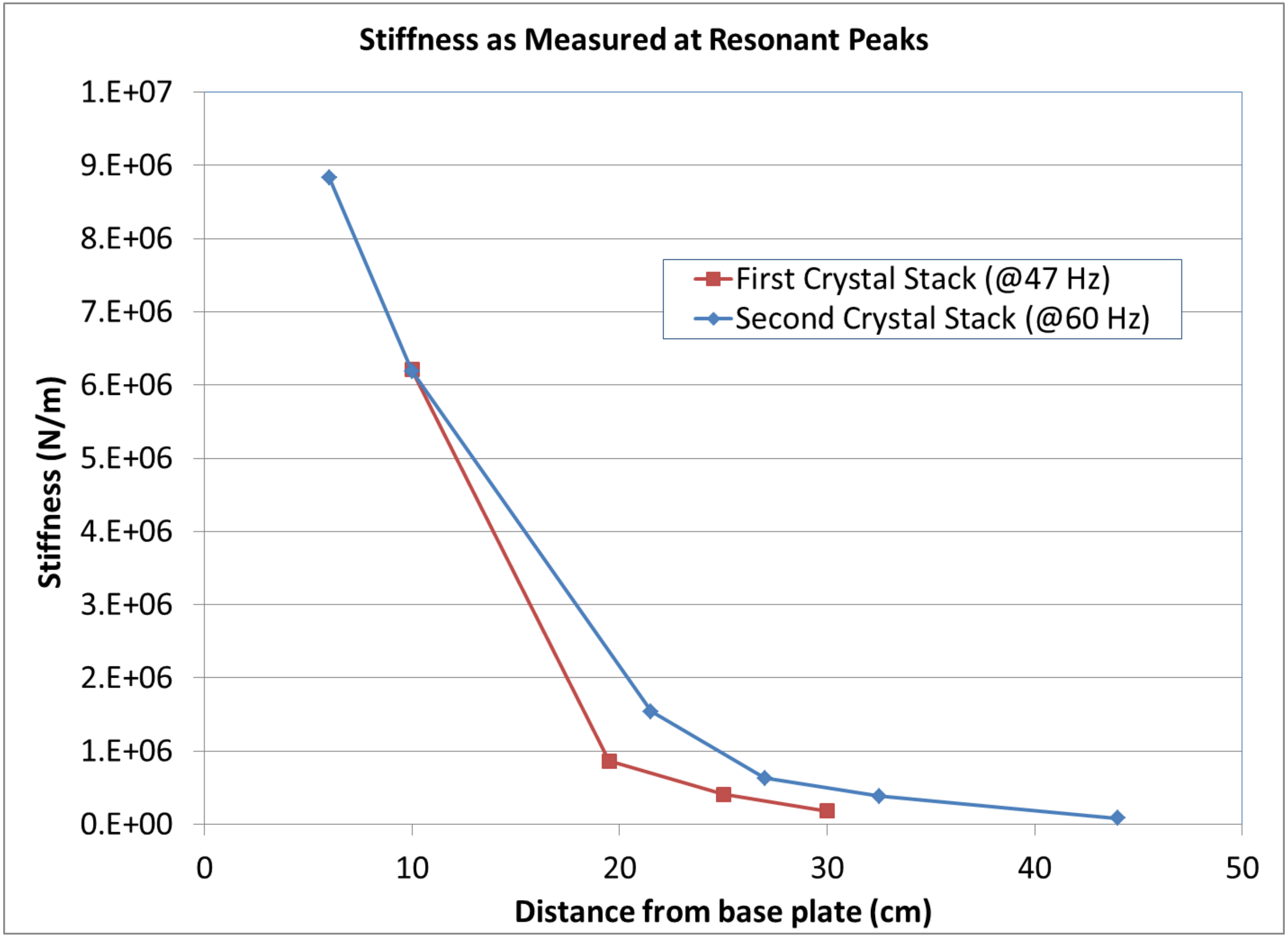


Case Study 2: Modal analysis

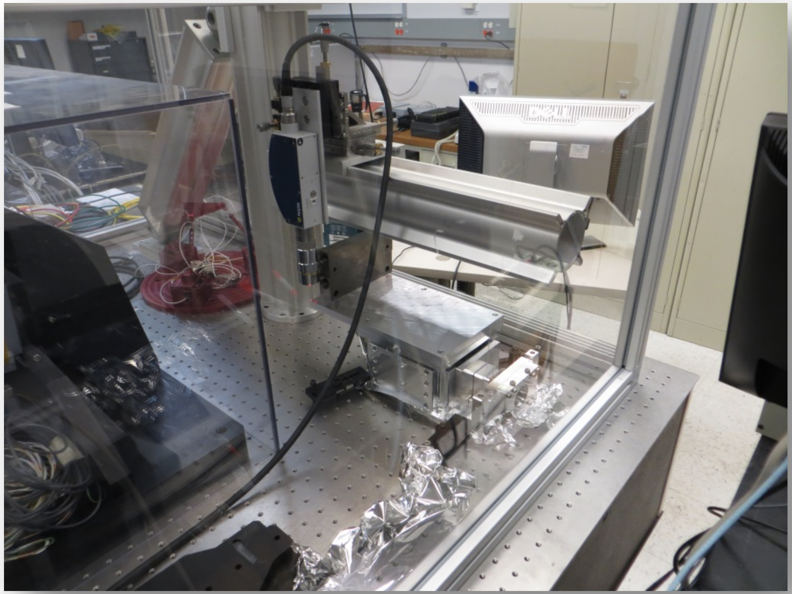
- Impact frequency response functions (FRFs) at each component of each stage stack provide:
  - Direct estimation of stiffness
  - Information to identify mode shapes and natural frequencies
- Each stack has a mode shape that is primarily in the Z direction (rotation about X), which is the worst for beam motion.
- 60 Hz mode for the second crystal stack is shown to the right
- Points 3-6 are moving portion of Y stage and above
- Y stage is "weak link"



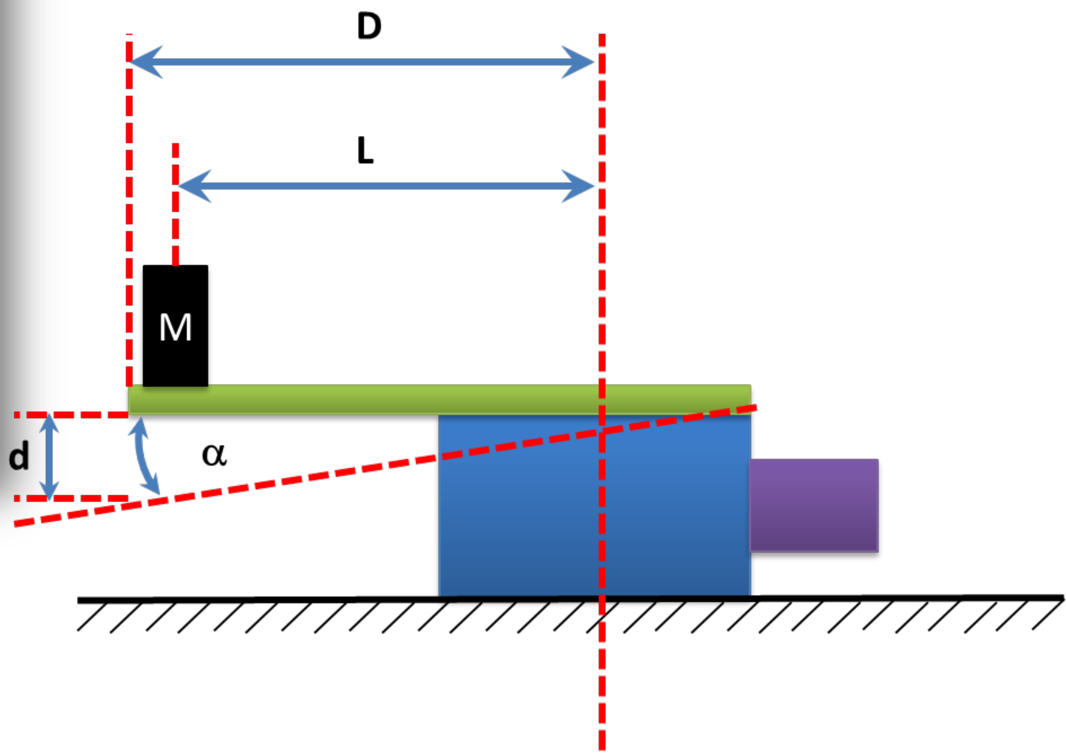
Case Study 2: Dynamic stiffness measurements



Case Study 2: Static stiffness measurement

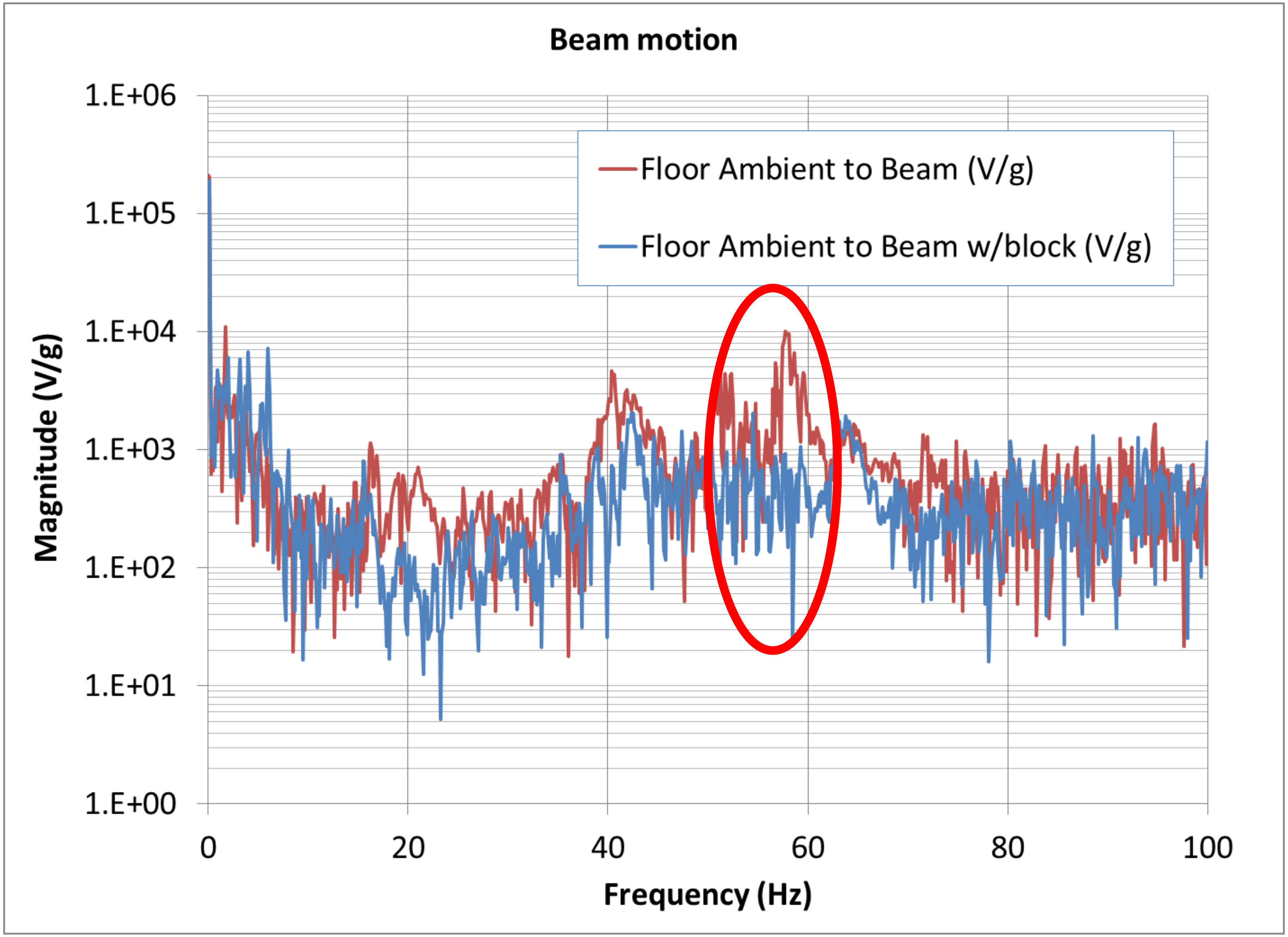


$$K_{XX} = T/\alpha$$

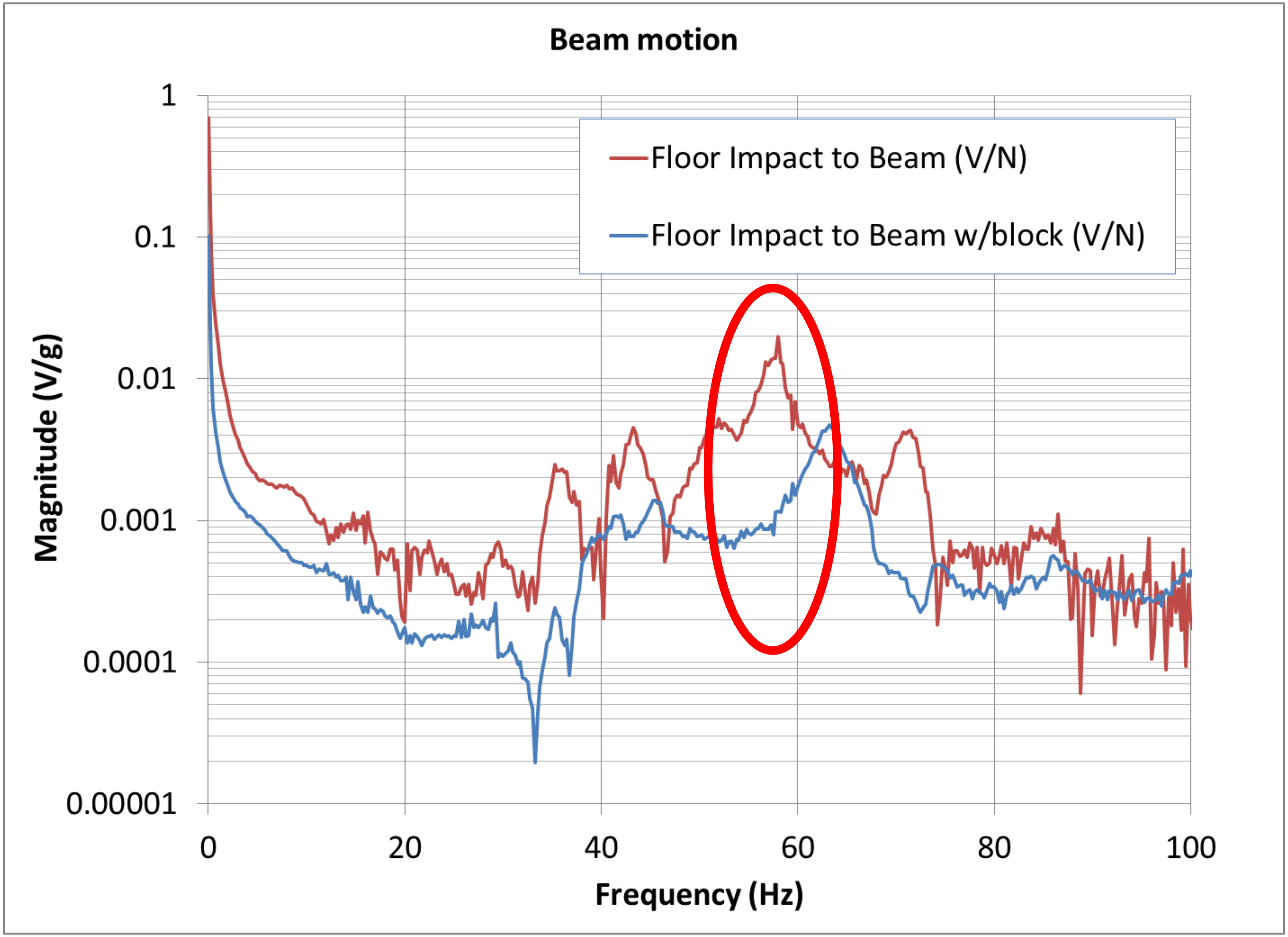


- Static stiffness measurement: ~37000 N*m/rad
- Dynamic stiffness measurement: ~18000 to 20000 N*m/rad
- This is *very* compliant as an APS-designed stage has stiffness of ~313000 N*m/rad

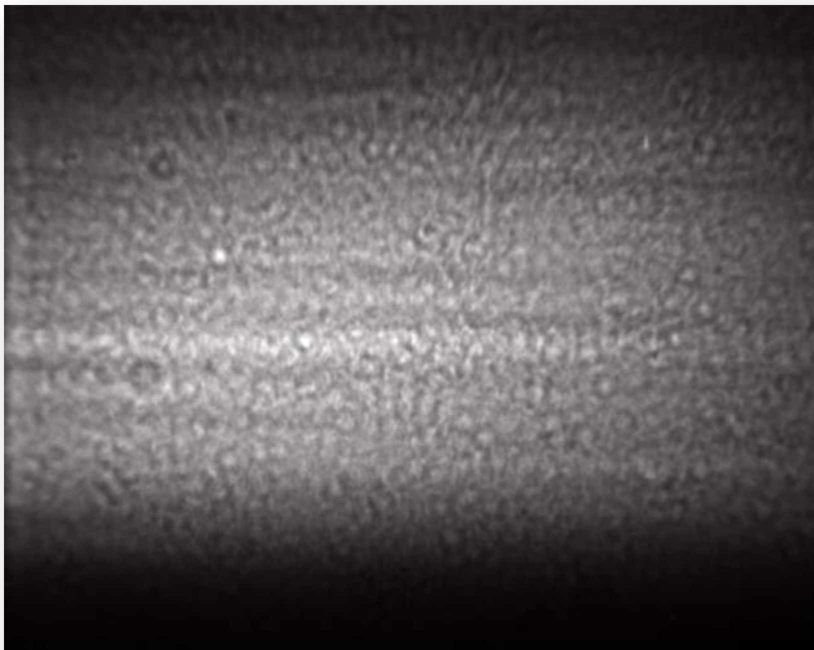
Temporary mitigation: Before and after



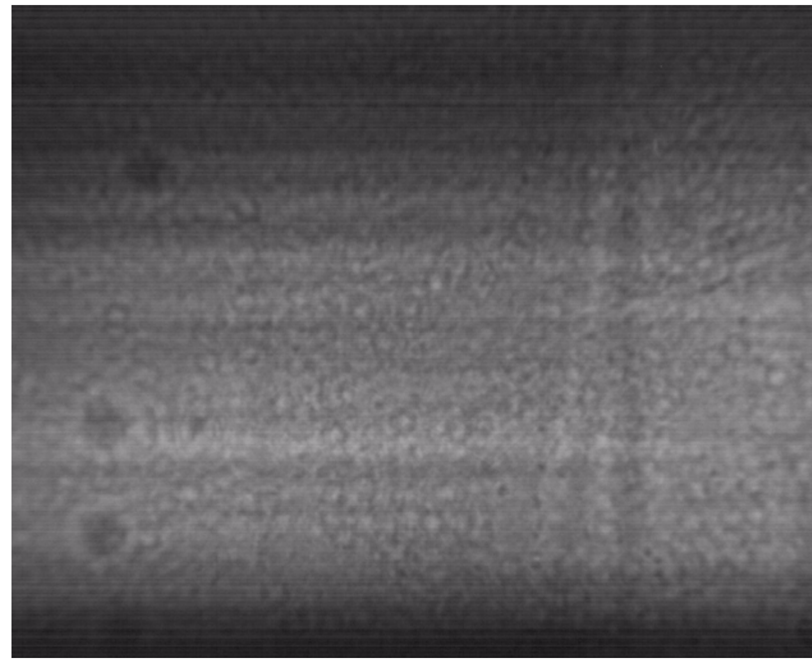
Temporary mitigation: Before and after



Temporary mitigation: Before and after



Before stage removal



With aluminum block

Summary of our method

1. Measure the ambient ground motion (level, sources, reference, support structure, etc…)
2. Measure the ambient beam motion
3. Try perturbing stages and measure beam motion
4. Measure beam motion FRF
5. Measure ambient motion of crystals/holders
6. Measure FRFs of crystal holders (modal parameters/stiffness)
7. Modal analysis of crystal motion system (identify mode shapes/natural frequencies)
8. Correlate beam motion and crystal motion/resonances
9. Remove/alter/replace suspect components

Recommendations

- Diagnosis
  - Check ambient environment
  - Measure beam motion with *sufficient bandwidth*
  - At some point, you need to open the tank
  - Modal analysis or impact measurements
- Good design practices
  - Reduce motion degrees of freedom
  - Select stiff bearings (both type and preload)
  - Use sufficient bearing separation
  - Hard points for cooling lines
  - Avoid cantilevered loads

Merci bein!

With my collaborators: Mark Erdmann, Alan Kastengren, and Barry Lai