# Carbon Fiber Laminates: Non destructive testing and inspection

Presented by Eric Anderssen
Lawrence Berkeley National Lab

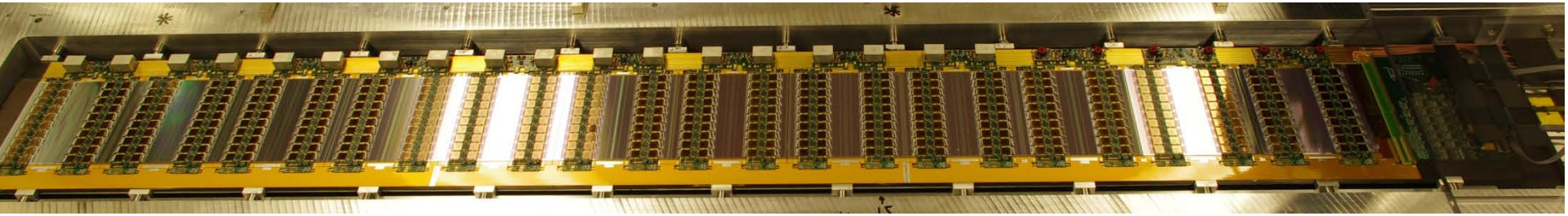
Haichen Wang, Sergio Diez-Cornell, and Carl Haber

# The ATLAS Phase-II Silicon Strip Stave

The stave is a supporting structure where the modules are mounted. It also provides data and power transmission between modules and End-Of-Stave (EOS) electronics by way of a co-cured flexible cable. Typical dimensions 1300 x 130 mm

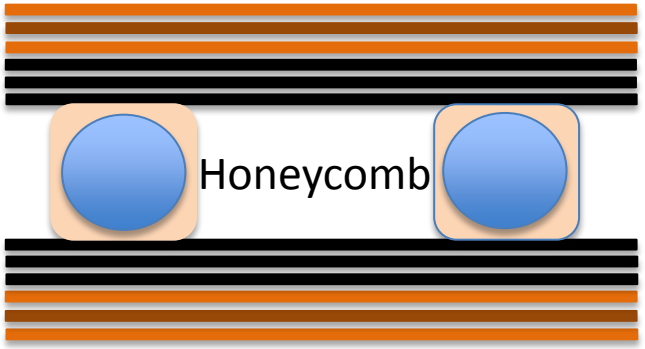
A full size stave

A full size stave with modules and EOS electronics mounted

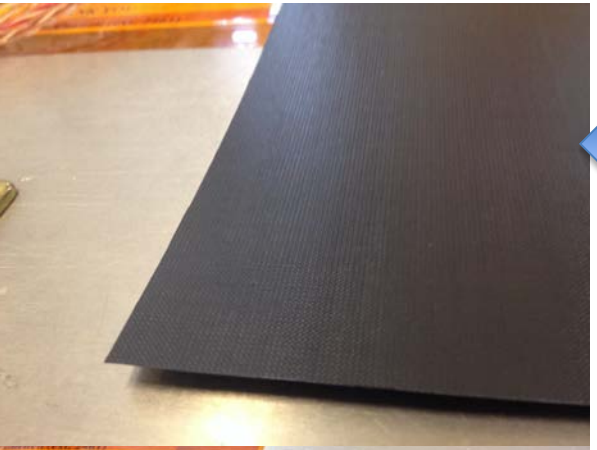


# Stave components and fabrication

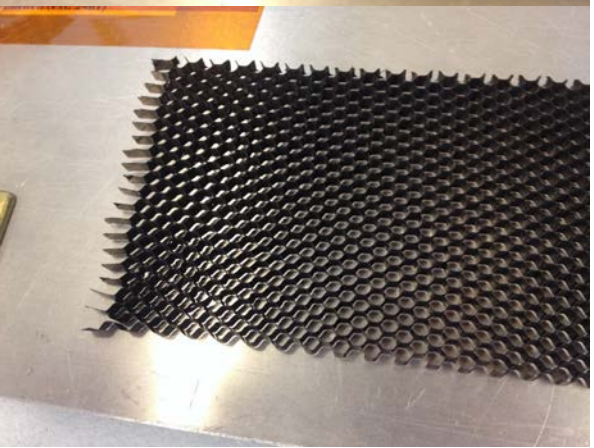
Bus tape: multilayers of kapton, copper, and glue that are co-cured

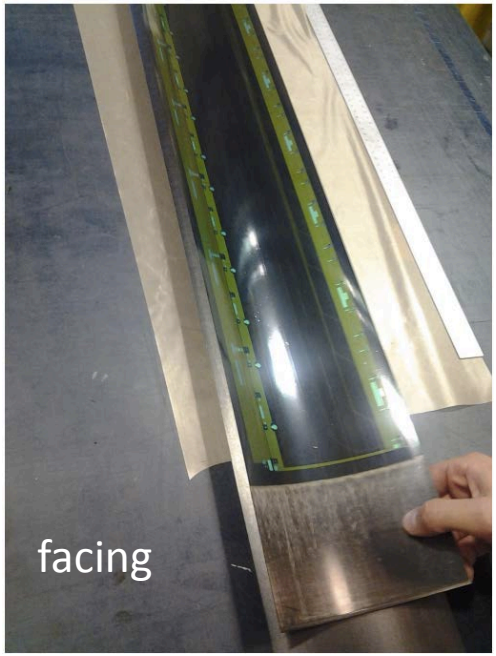


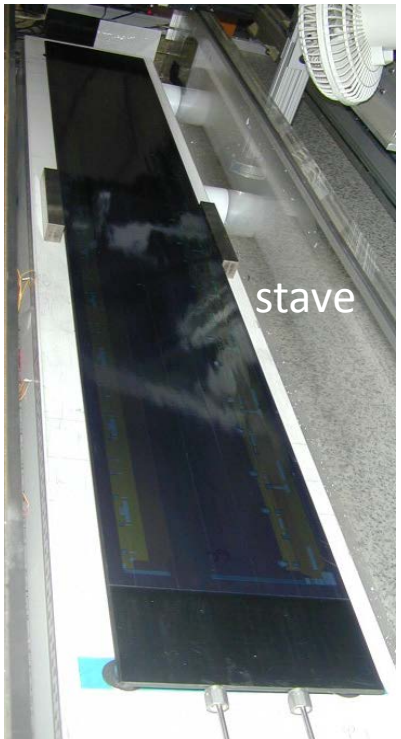

Titanium cooling piples
High thermal conductive foam



Carbon fiber facing: three layers of carbon fiber that are laminated





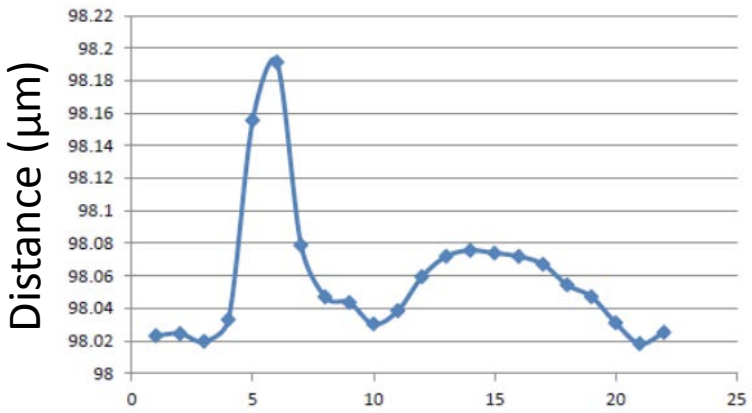



# *Non-destructive testing and inspection*

- QC is needed to find electrical and mechanical defects and to establish precision metrology
- Broad effort to develop robust and scalable tools
- Precision metrology: video inspection
- Visible defects: image analysis
- Delamination and missing glue: acoustic detection

# Example of defects on the stave

A defect found on the full size serial power stave.




Distance between HV contacts on the stave for two adjacent modules

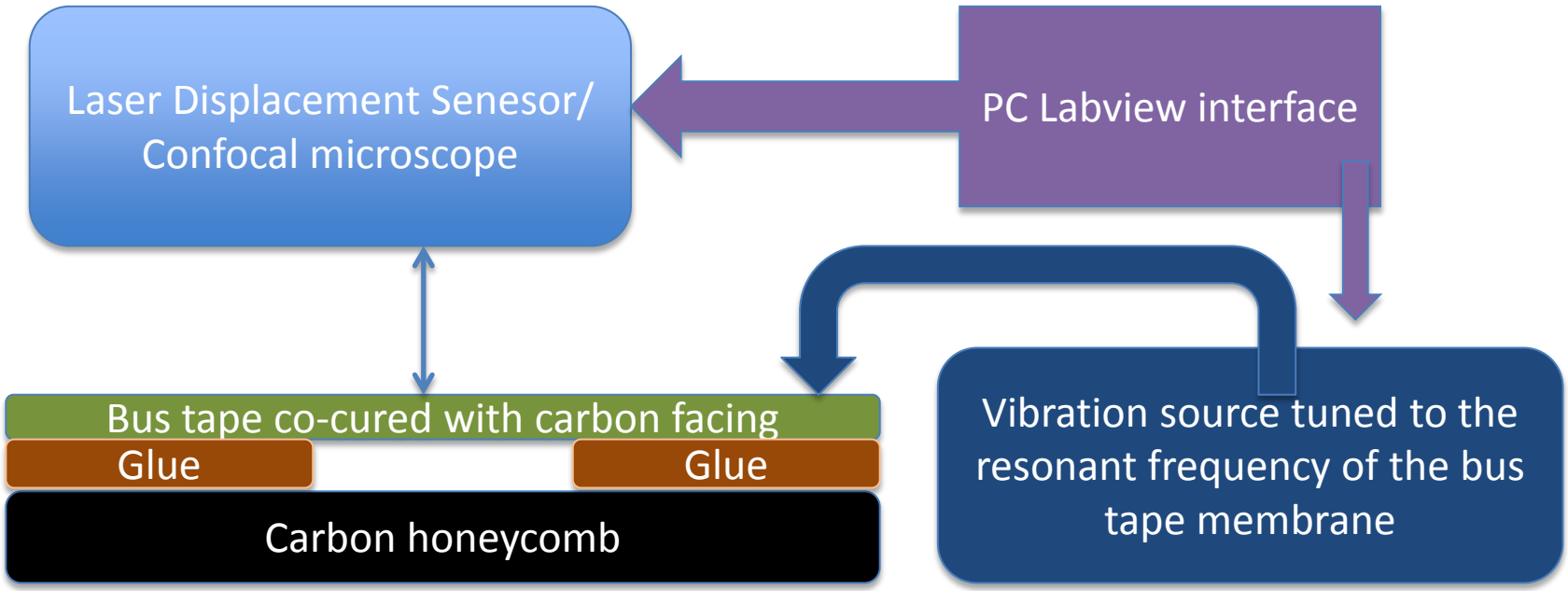
This particular defect was believed to exist on the laminated facing but made its way to the stave.

Defects like this speak of the necessity of building a quality control system.

# Delamination stave sample


The composite shop at LBNL made stave samples ( ~100 mm × 130 mm) with glue void in the center. The diameter of the glue void varies from 5 mm to 20 mm.

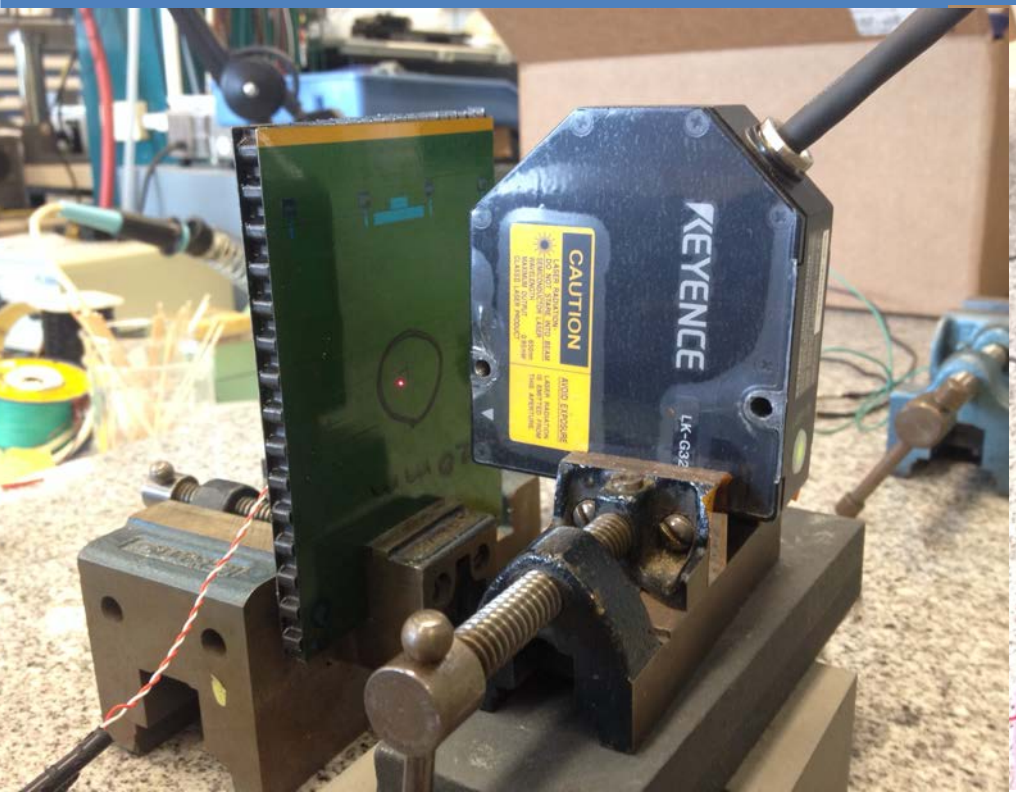
# Concept of the acoustic detection system

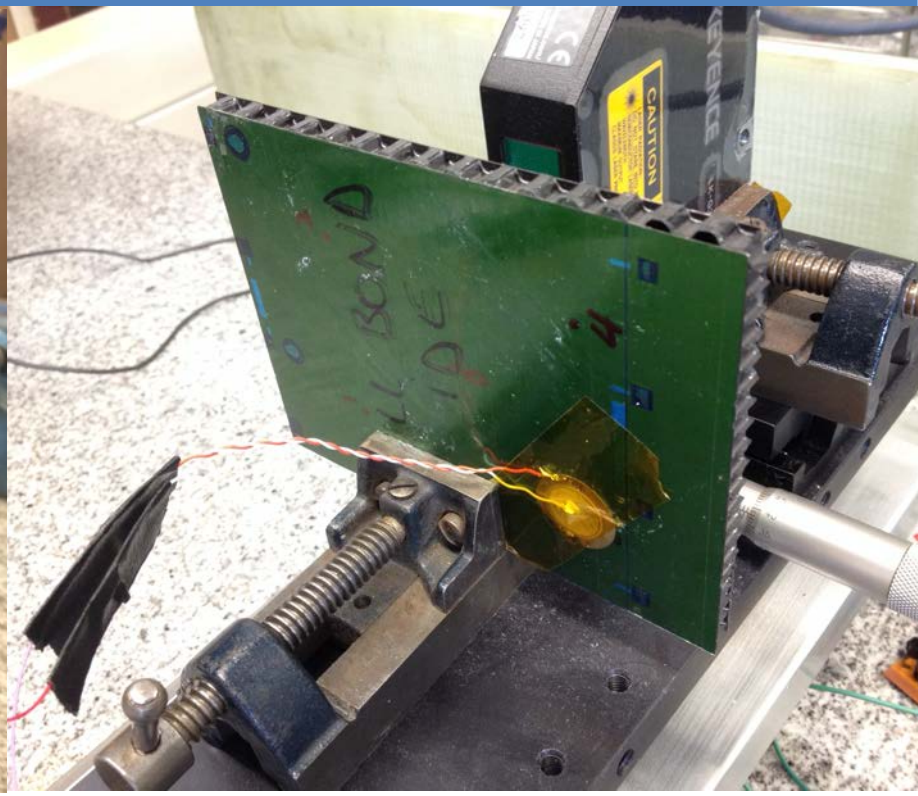




Laser Displacement measurement device. ~0.5 μm precision.
Later will upgrade to a confocal microscope with nm precision.

# Measurement setup

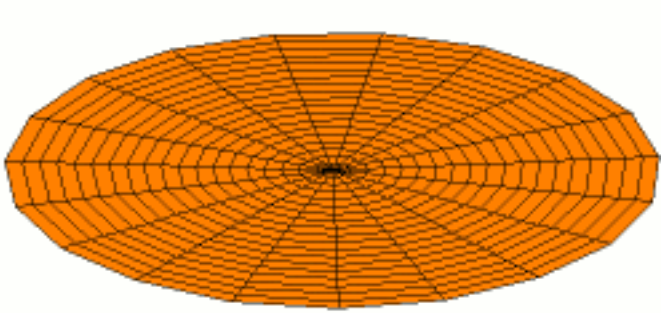



- The measurement is done on the same side of the defect.
- The piezoelectric device is placed on the opposite side of the stave sample. The position is chosen not to be coincident with the defect position.
- Vibration was generated by Wavetek 150 or NI PXI 4461.

# *Theoretical model: vibrations of a circular membrane*

A circular membrane where the edge is fixed. The allowed frequencies of harmonic vibration are solutions to the Bessel equation.



$$\nu_{01} = 0.38274*\mathrm{sqrt}(T/\sigma)/a\ .$$

T, the tension at the edge; σ, the density of membrane; a, the radius of the membrane. *"Vibration and Sound" P.M. Morse.*

$$\nu_{01} = (10.2/pi)*\mathrm{sqrt}(D/(\sigma\ (r\text{^}4))).$$

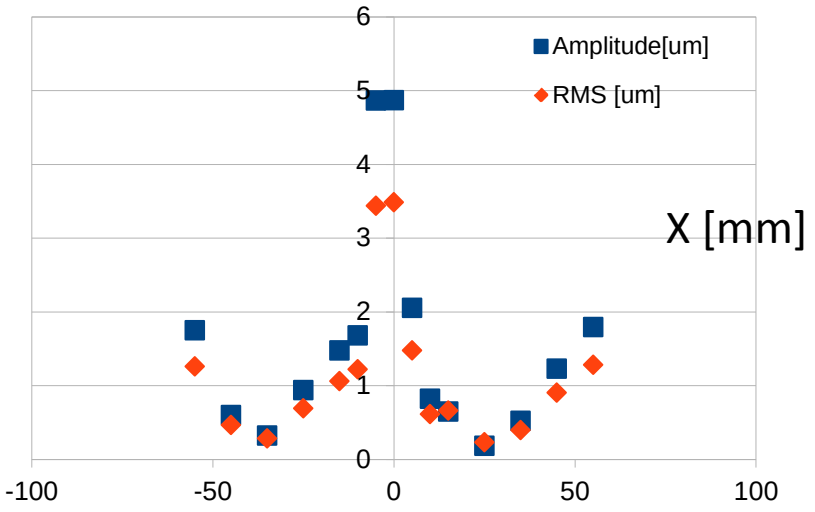
D =Et^3/ ( 12*(1-u^2)). E, Young's modulus, t, thickness of the membrane; u, poisson ratio; r, radius of the membrane. *"Roark's Formulas for Stress and Strain" 7th Ed.*

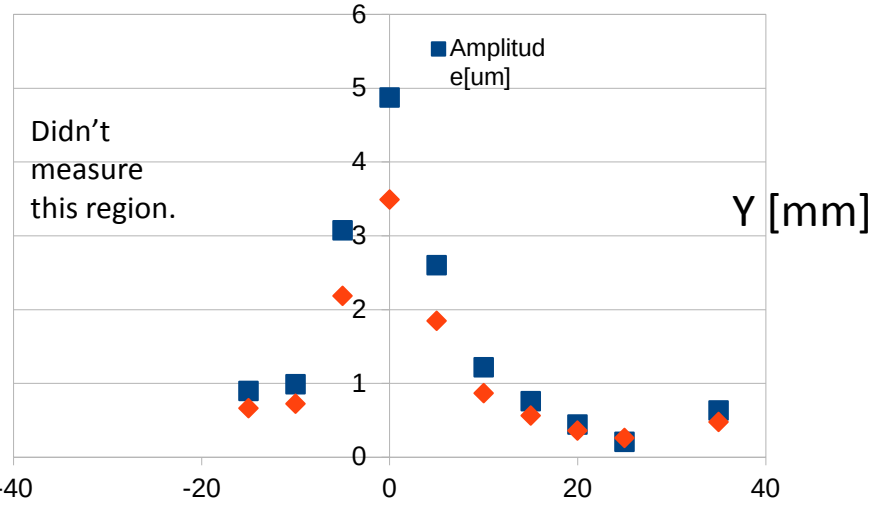
Situation further complicates when

- There is a loading, and the loading is not uniform;
- The material is not isotropic or not uniform;
- Boundary conditions are not well defined;
- *In fact we cannot get data to match a simple calculation*

# Measurement from Sample 1 (20mm)

- Point the laser to the center of defect and tune the frequency to find the maximum displacement.
- Use this “resonant frequency” as input, scan the surface of the stave sample.
- Resonant frequency found at ~7500 Hz
- Edge effects due to lack of closout

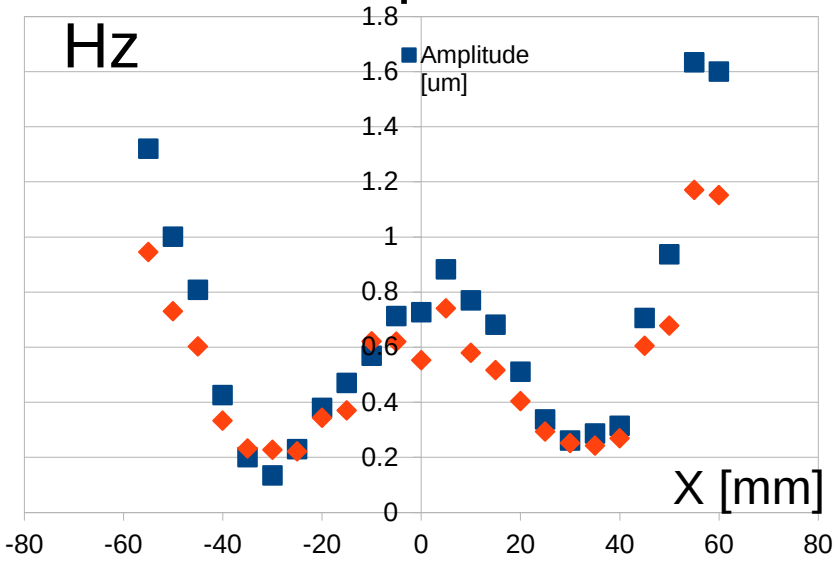



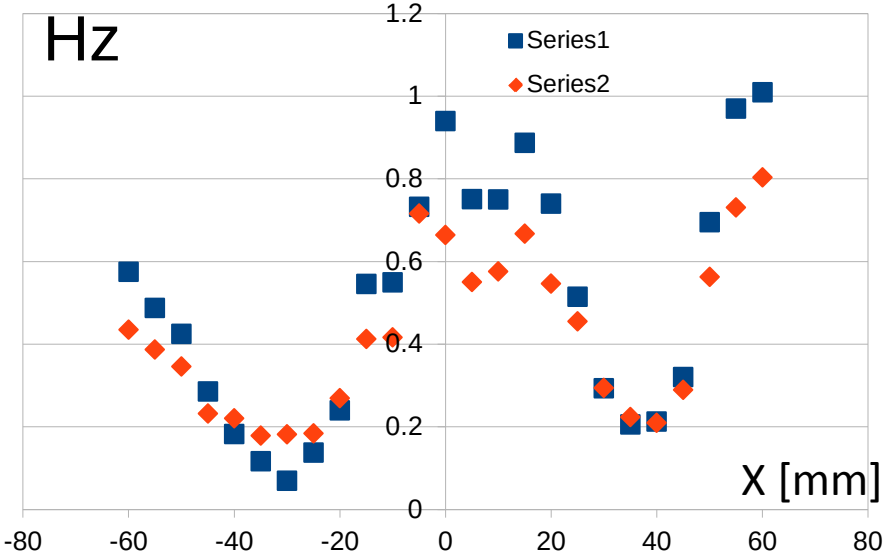
# Measurement from Samples 2,3 (10, 5 mm)

- Repeat the procedure on the 10 mm and 5 mm samples.

10 mm sample at ~7500 Hz



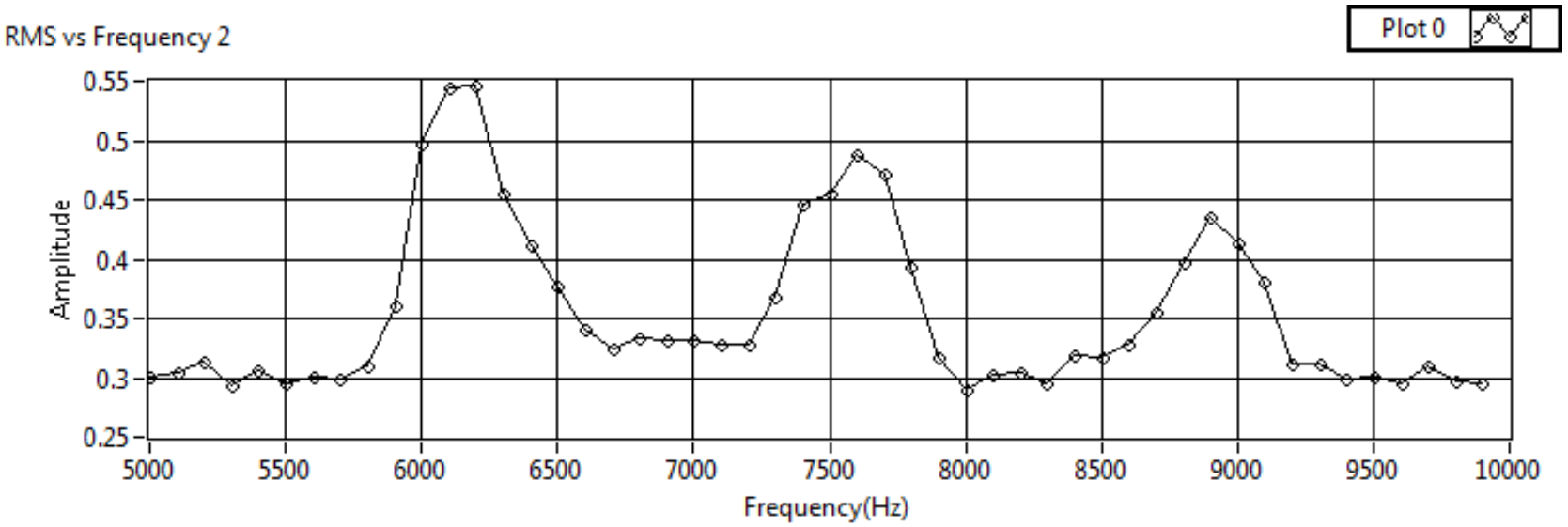

5 mm sample at ~8500 Hz



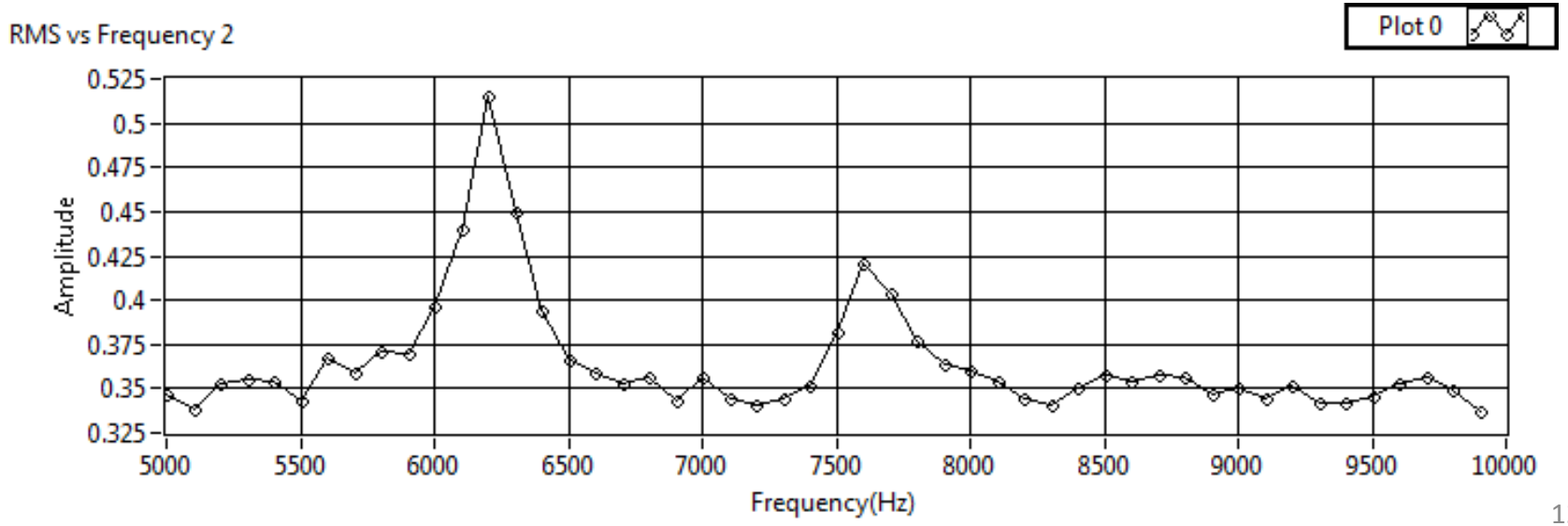

- Similar results were found.

# Frequency scan in the region of defect

RMS of amplitude measured at the center of the defect for the 20 mm sample

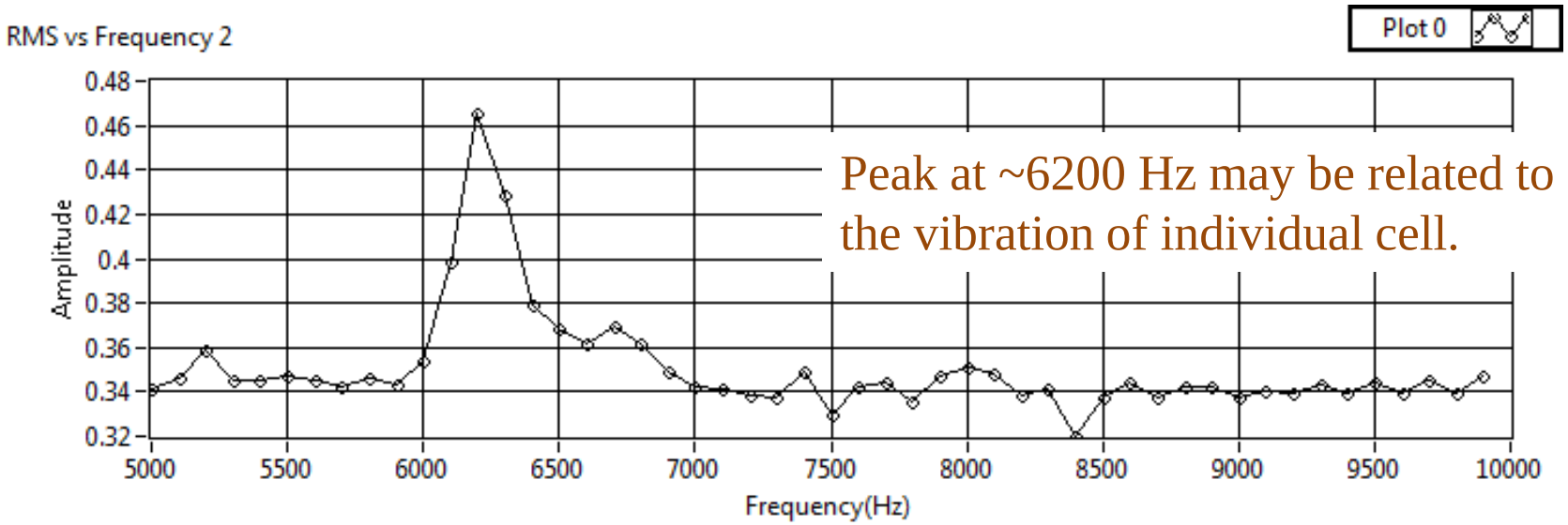



RMS of amplitude measured at the center of the defect for the 5 mm sample



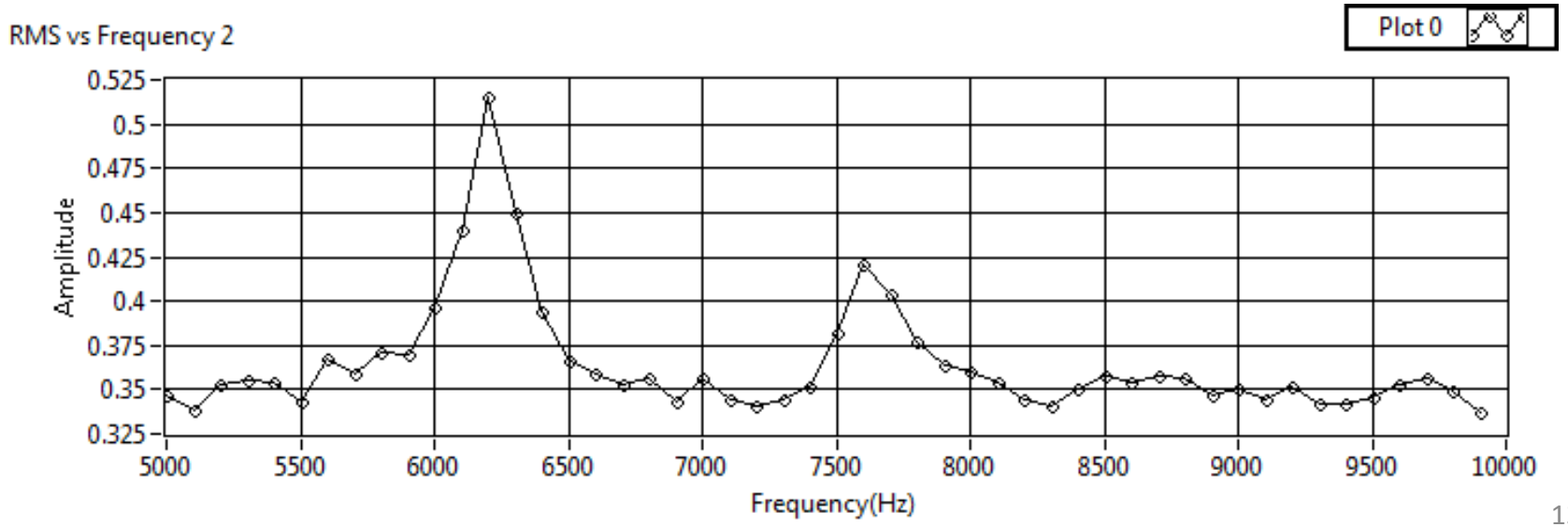
# Frequency scan in a good region

measured at a position that is 35 mm away from the defect for the 5 mm sample



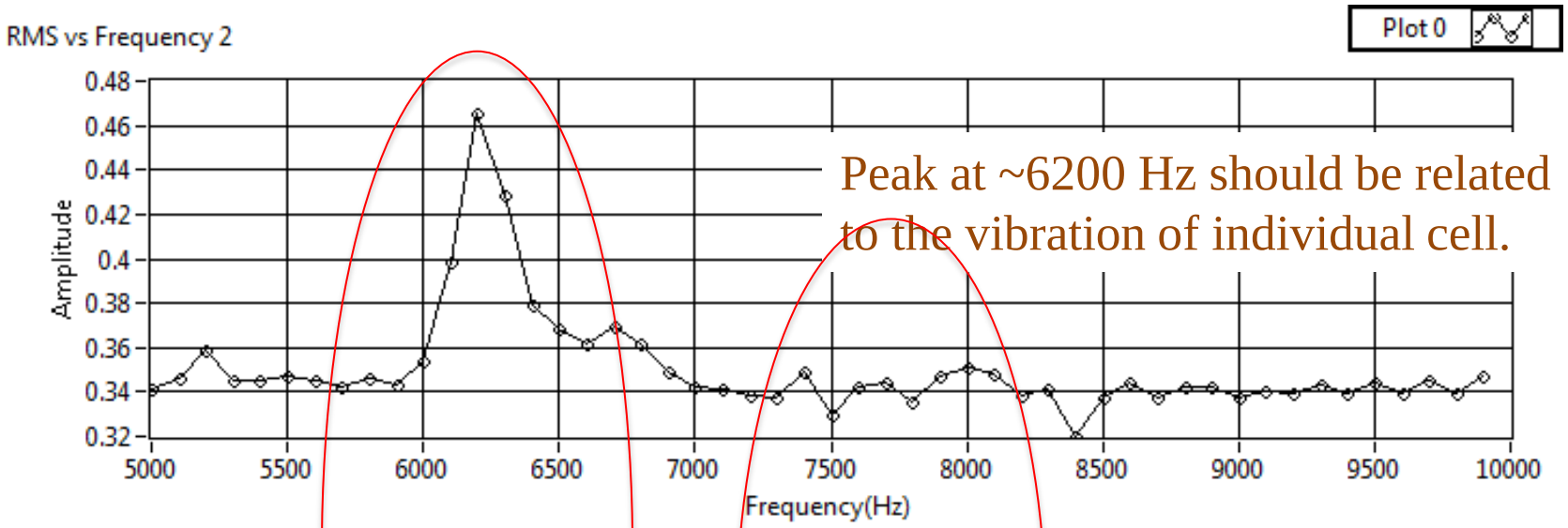

Peak at ~6200 Hz may be related to the vibration of individual cell.

measured at the center of the defect for the 5 mm sample



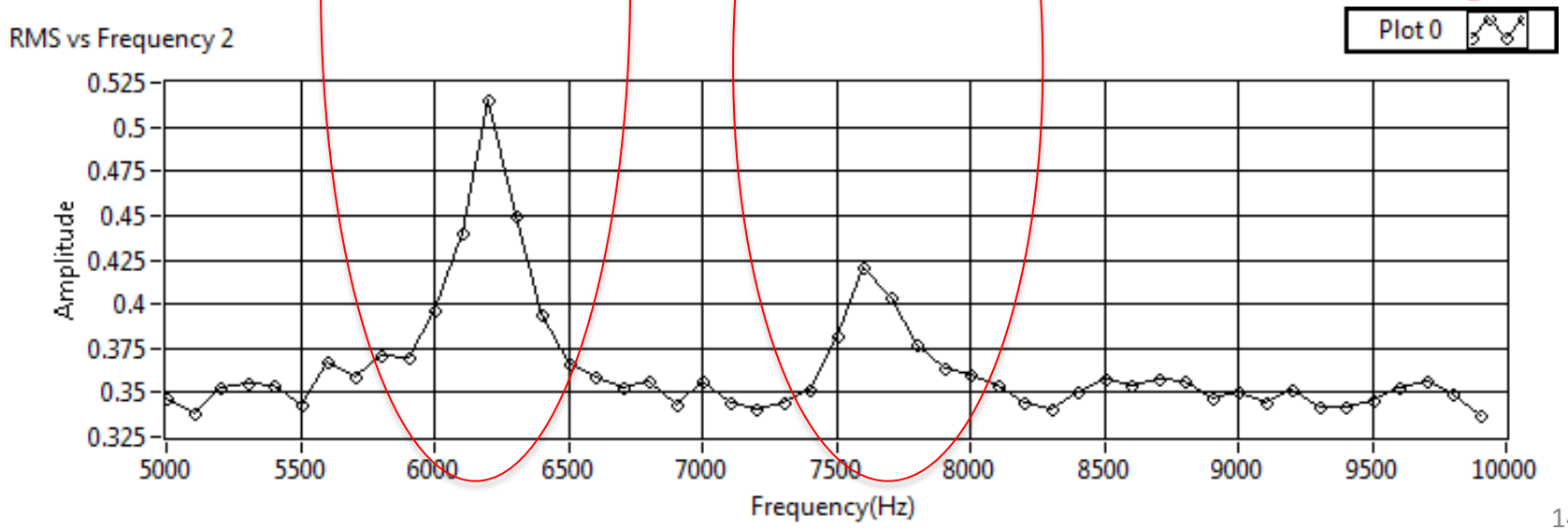
# Frequency scan in a good region

measured at a position that is 35 mm away from the defect for the 5 mm sample




Peak at ~6200 Hz should be related to the vibration of individual cell.

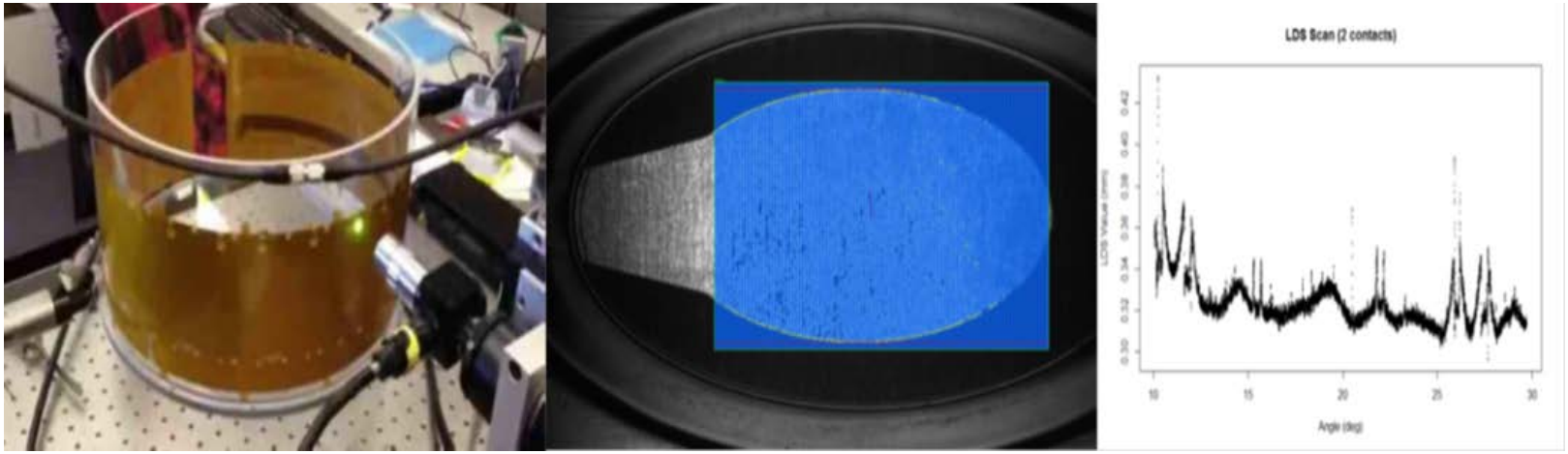
measured at the center of the defect for the 5 mm sample



# *Metrology*

- Components including CF and kapton bus tapes can undergo deformations during cure and cooling.
- Important to inspect and measure repeatedly through the fabrication process
- Developed a fast scanner to pre-screen and measure bus tapes before co-cure.

# Tubular Scanner

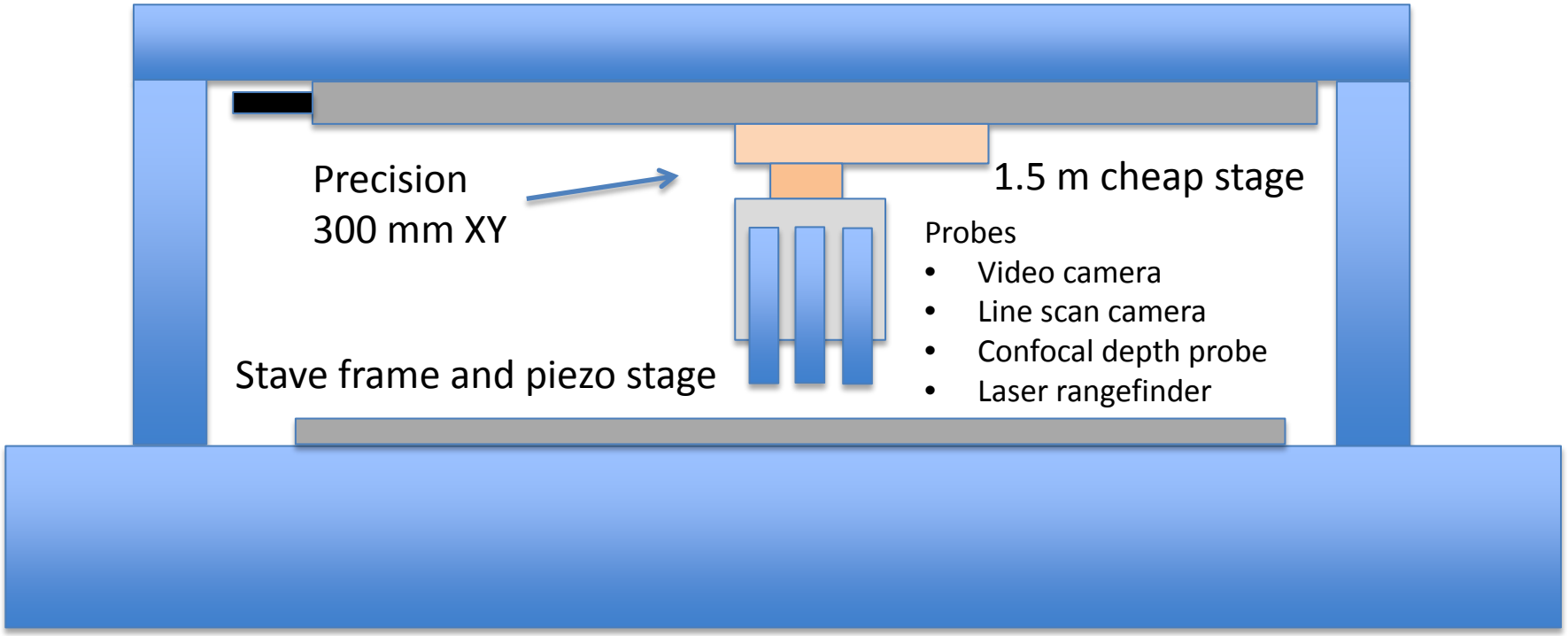



- Wrap flex tape cable around a cylinder, spin (72 seconds)
- Use line scan camera to capture high resolution image of the entire tape
- Use image processing tools to extract precision metrologic data from cable features
- Use 3D surface profiling to control focus and distance

# Large Inspection Station

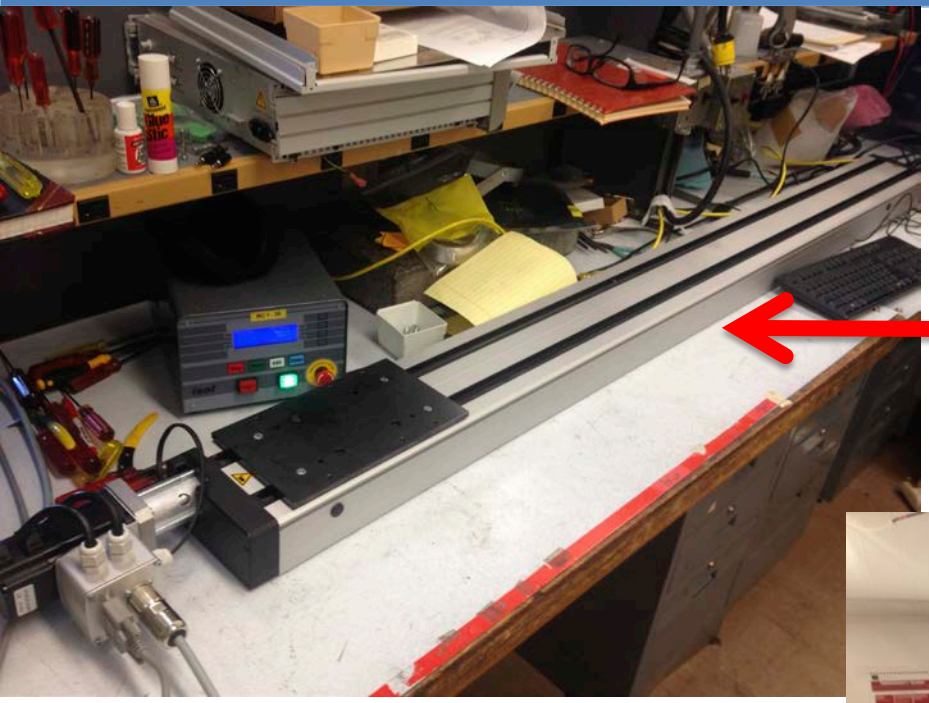
- The methods show sufficient promise that we are scaling them up to a full sized system.
- Once tapes are co-cured they need to be measured flat as well.
- A Stave frame: a tool to hold facings and staves
  - Local fiducials near each sensor to establish ref.
  - Vacuum base has peizo array built in for optional vibration
- Probe Set
  - Video camera for alignment and inspection/doc
  - Line scan for high speed metrology and trace inspection
  - Confocal for precision depth profiles and vibration measurements for defect finding
  - Laser for fast profiling and defect finding

# Design of Large Inspection Station




Frame

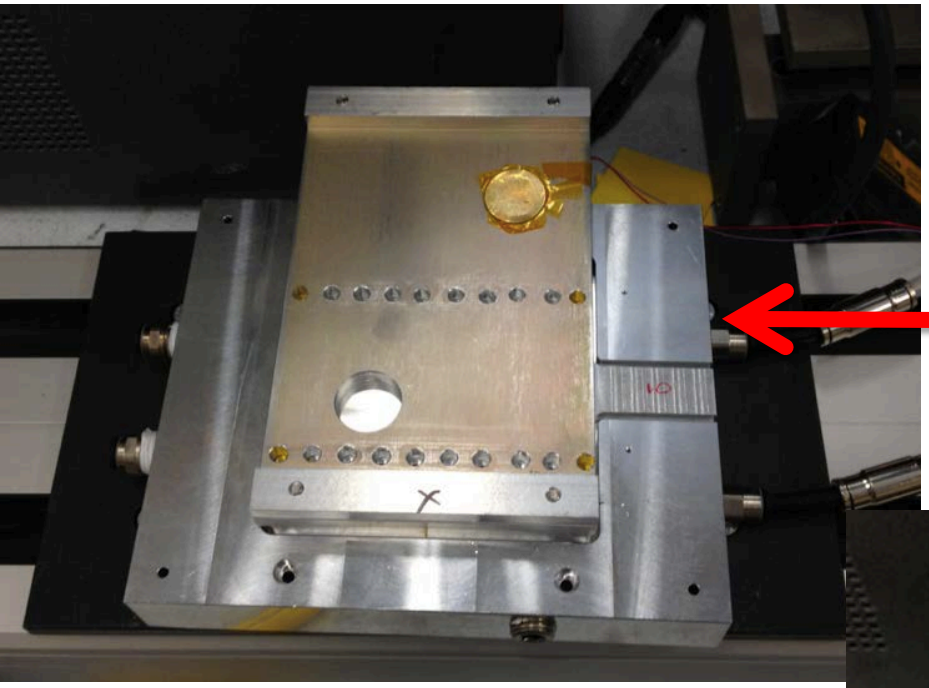
# *Towards an integrated system*



A 1.5 m long stage where the inspection system will be mounted.

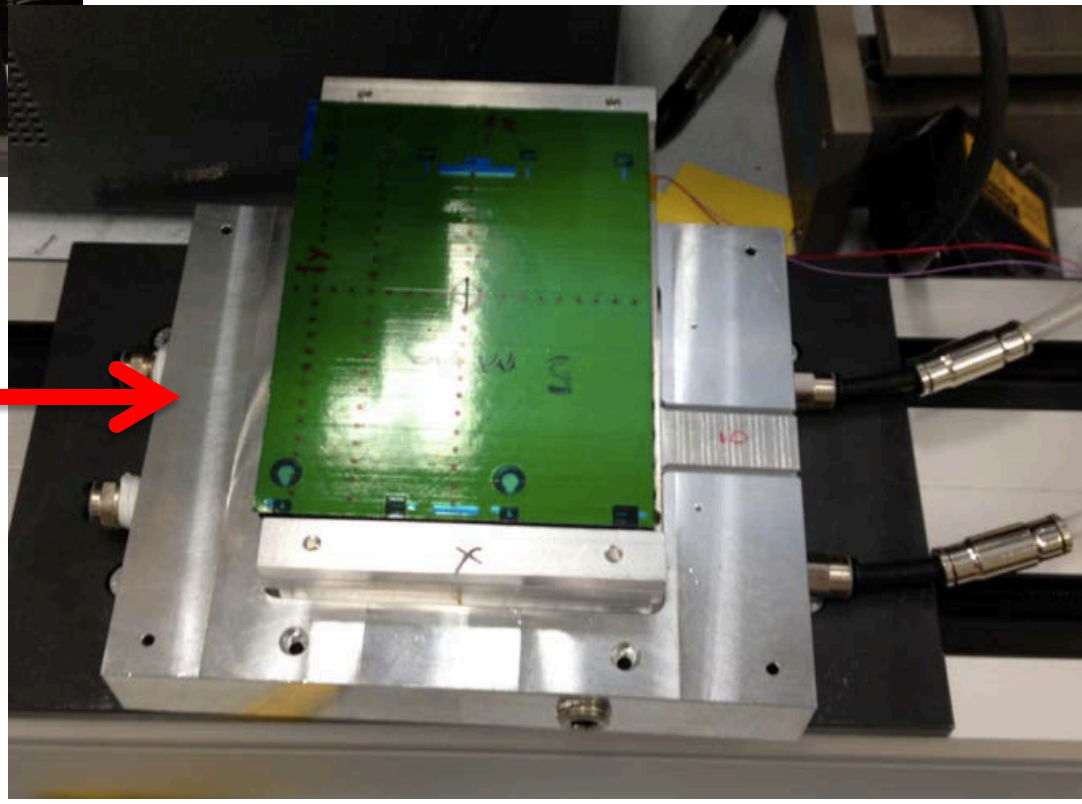
An optical table that will host the stage and the inspection system.

# *Piezo-vacuum fixture holding the stave*



A pedestal with openings is sitting on top of a vacuum jig.
The piezo disks are placed in trivial positions.

The stave core sample is held by the pedestal.
A new pedestal that provides better vacuum integration is being built.



# Summary

- We have demonstrated the feasibility of using an acoustic non-destructive testing method to discover defects on a stave.
- Deliberate defect samples were fabricated for this purpose.
- The sensitivity of this method can reach to at least the 5-10 mm level.
- The displacement sensor will be upgraded to a confocal microscope that has a precision at nanometer level.
- A fast line-scan based system for precision metrology was also demonstrated.