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Cryomodule Impulse Hammer Testing

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PIP-II Weekly Meeting

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Impulse Hammer Testing

- Unexpected mechanical resonances are one of the major concerns for new cryomodule designs.
- Impulse hammer testing is a controlled method of stimulating vibration that can be straight-forwardly correlated with response.
- A piezoelectric sensor in the hammer (Piezotronics 086D20 Short-Sledge) produces a signal proportional to the applied hammer force.
- This can be correlated with other sensors (accelerometers, geophones, etc.) on the structure to calculate direct transfer functions from impact site to sensor.

Cavity/Cryomodule Testing

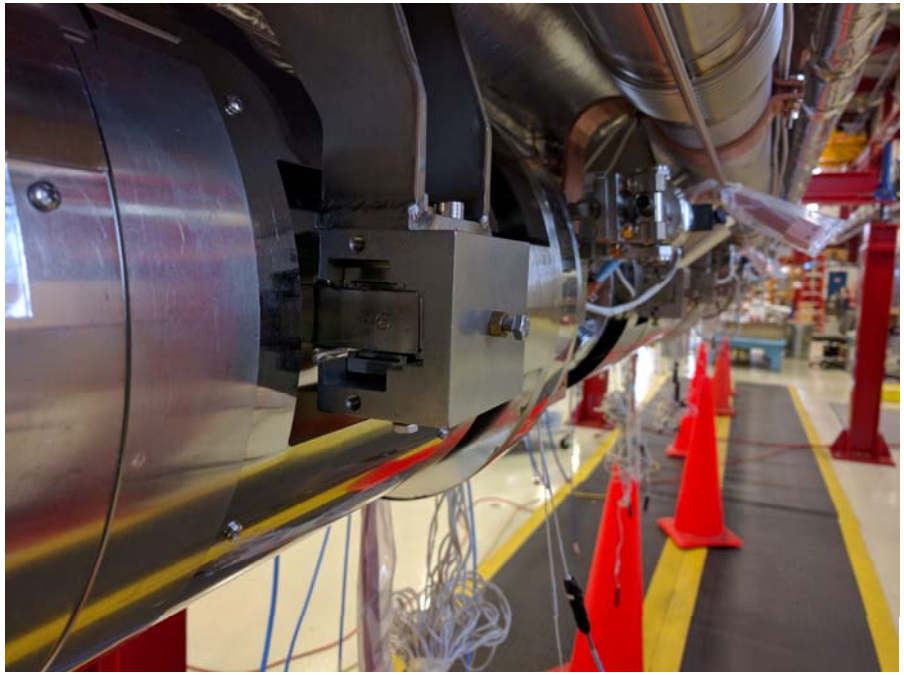
It's highly desirable to do testing on all cryomodule substructures at various stages of assembly:

- Bare/Dressed Cavity
- Cold Mass
- Full Cryomodule

The LCLS-II pCM was available for testing, starting from an assembled cold mass.

Piezo tuners were used as sensors.

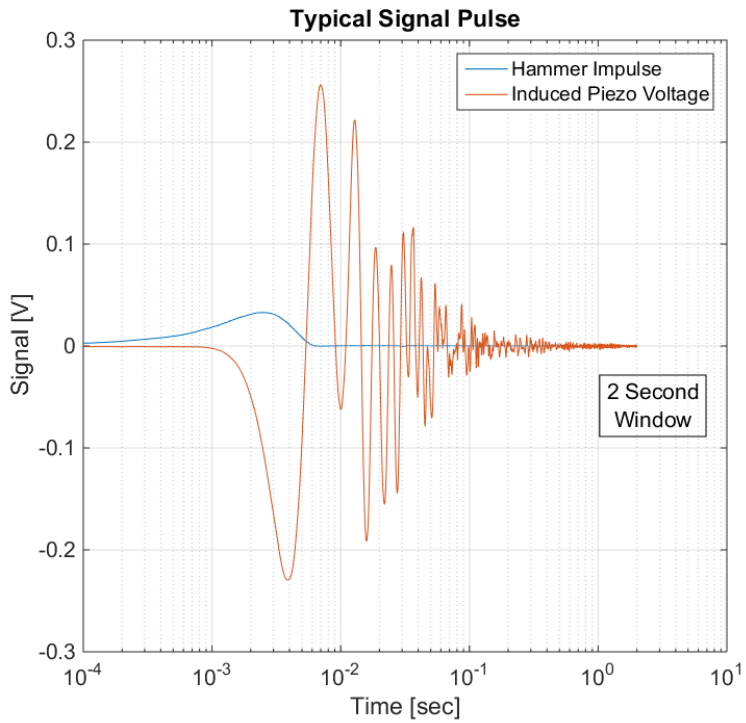
Testing Configuration

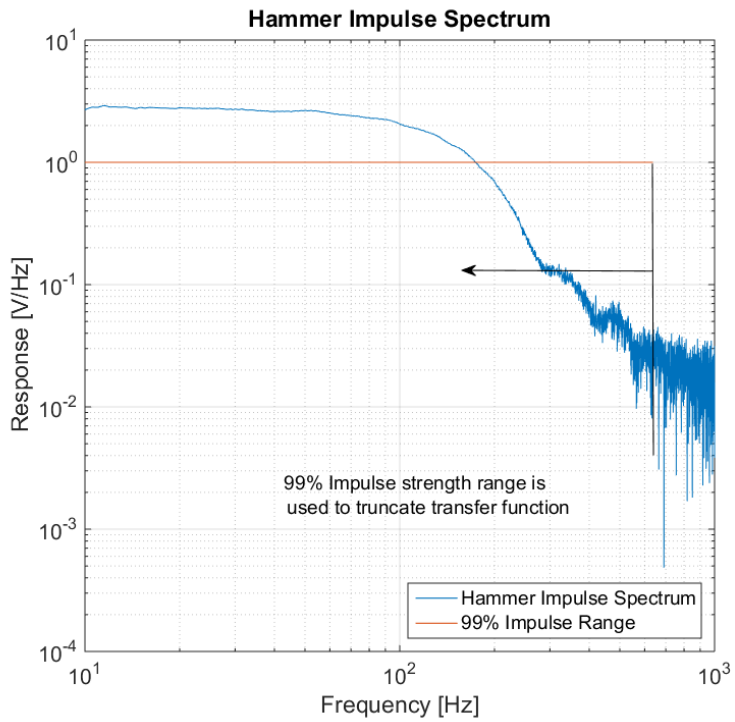


Some testing was done on the assembled cold mass before insertion into the helium vessel.

Further testing was done after insertion when it was hanging from the cryomodule supports in a more realistic configuration.

Typical Measurements





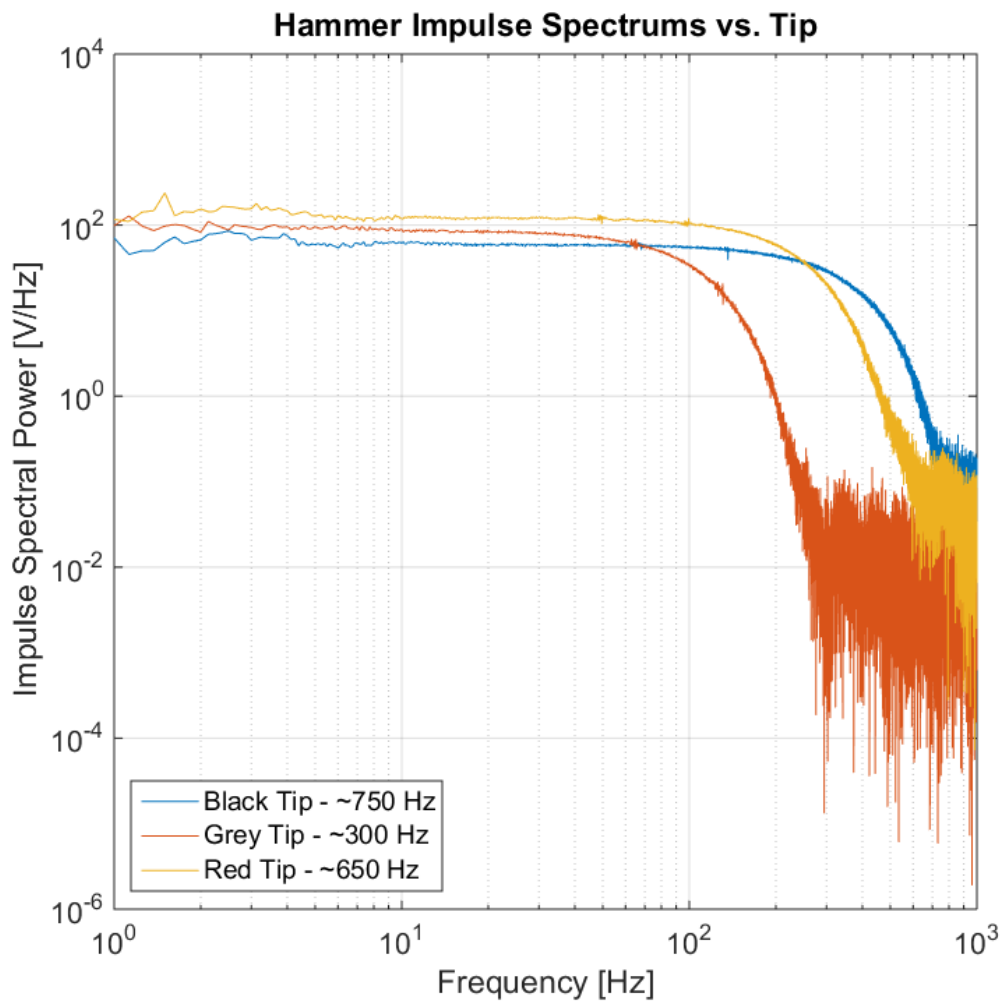
All four piezo stacks were wired in parallel to amplify signal. Hammer was measured through signal conditioner.

Depending on the hammer tip used, the impulse spectrum rolls off between 200 Hz and 700 Hz. Heavier blows and softer tips drive low frequency modes better.

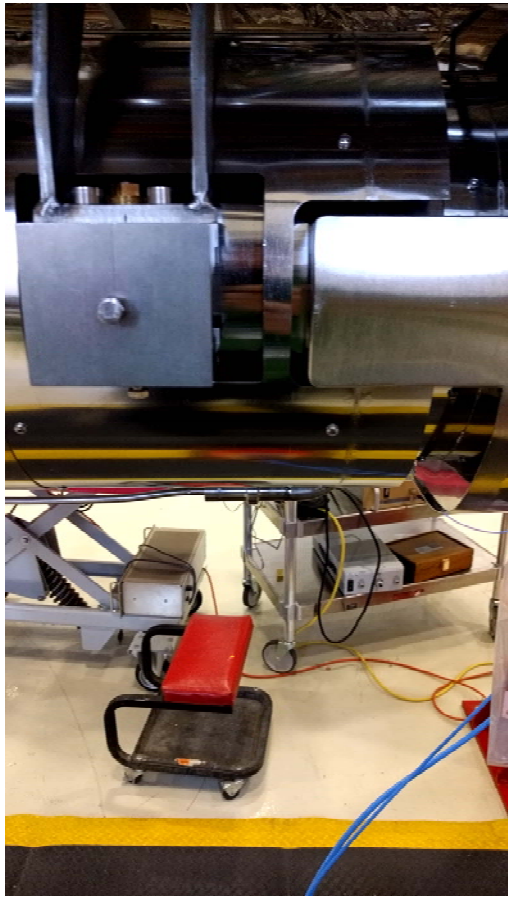
Different Tip Stiffness

Cold mass measurements were done with Red Tip without backing weight.

Cryo vessel measurements were done with all three tips with backing weight for additional stored energy.



Impact Force

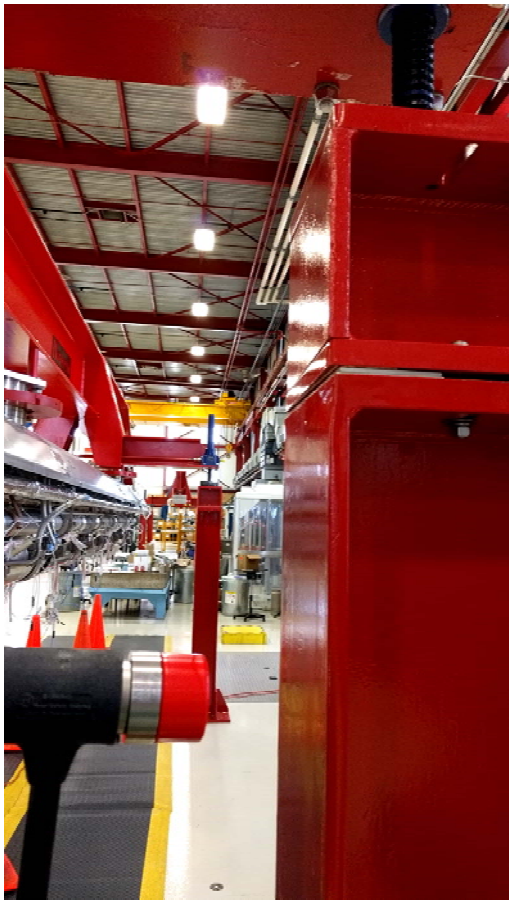


Because the measurement is relative, each blow doesn't need to be exact. However, certain areas are more delicate than others.

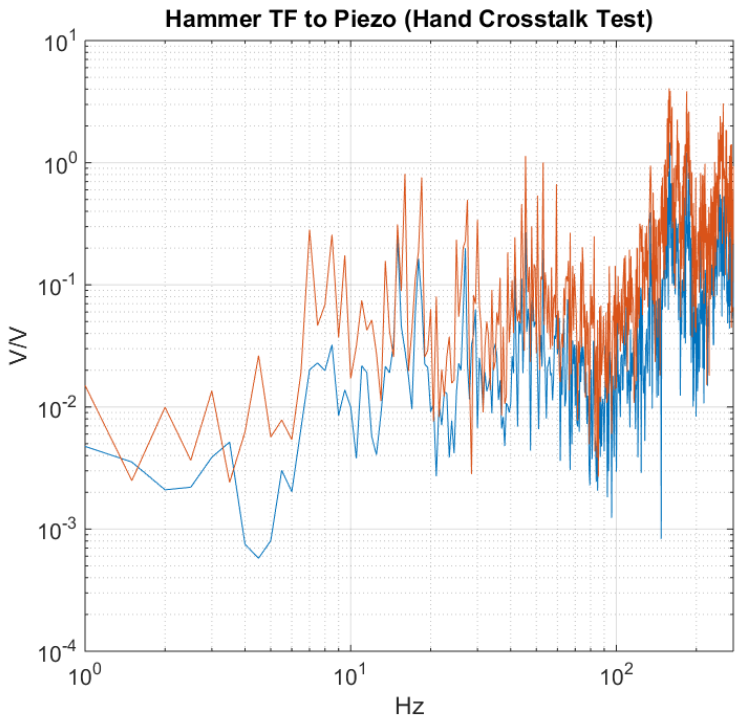
Softer blows on the tuner still produced very strong response.

For more structural components, heavier blows and softer tips were used.

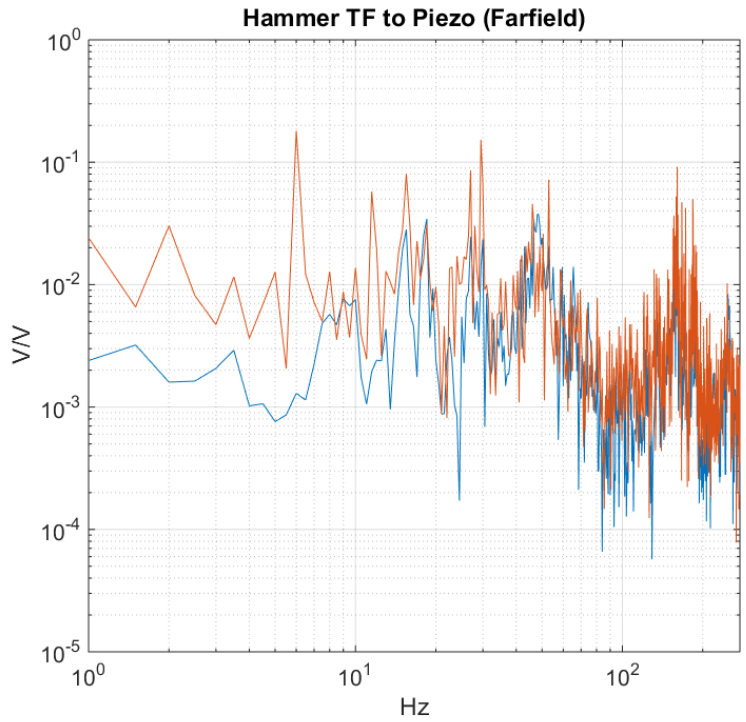
Listening closely in both movies, high pitch rattles can be heard from loose hardware.



Sanity Tests

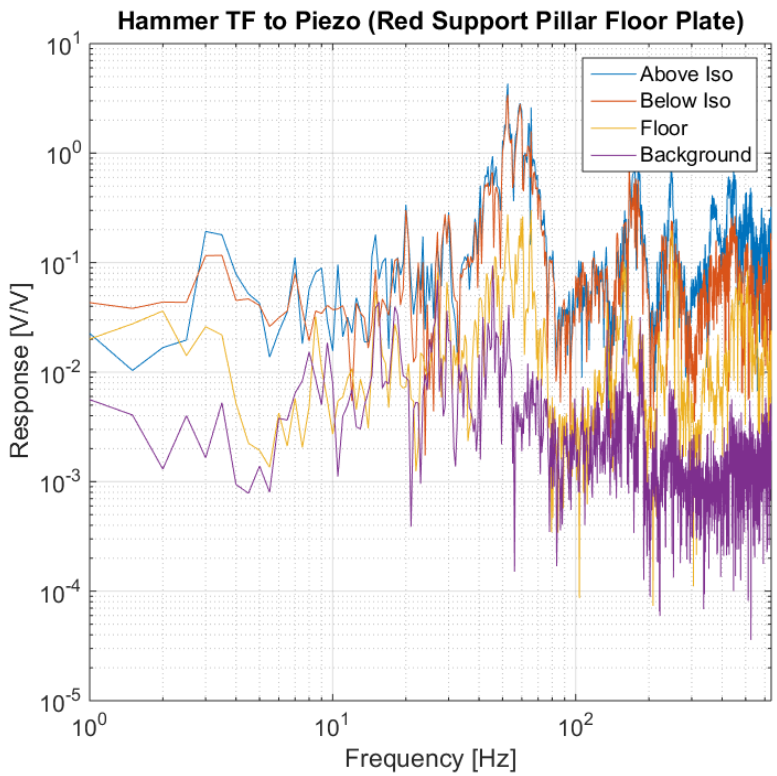


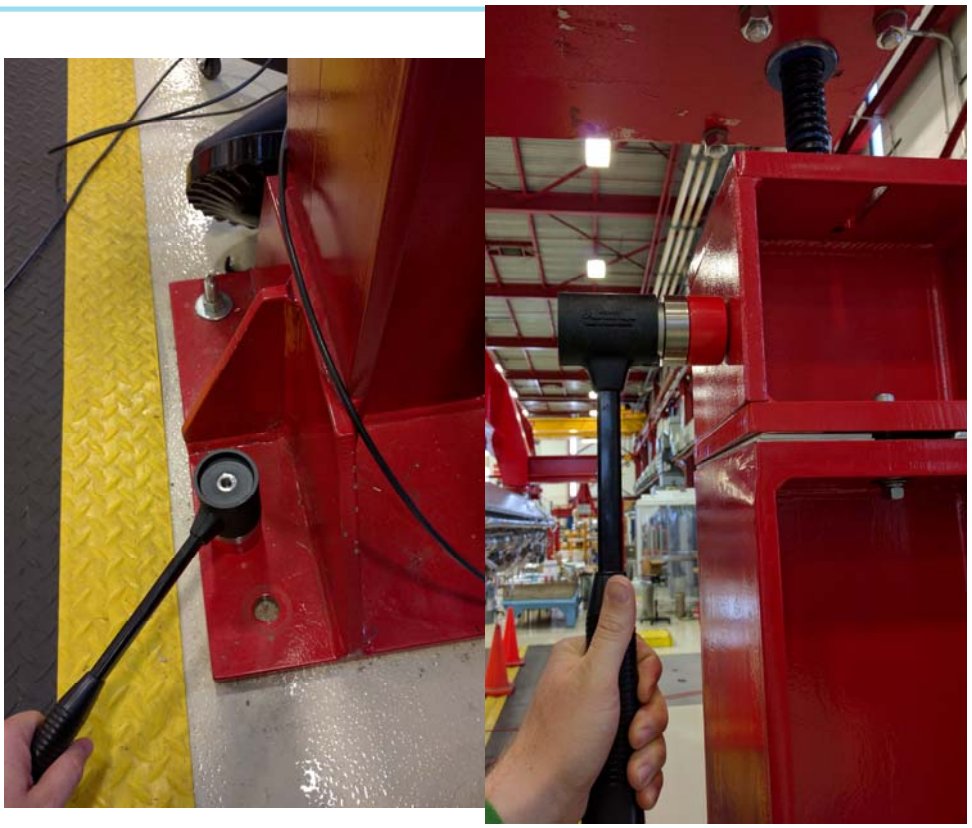
Impact on hand to test for any crosstalk in the DAQ system.



Hard impact on ground as far as cabling would allow.

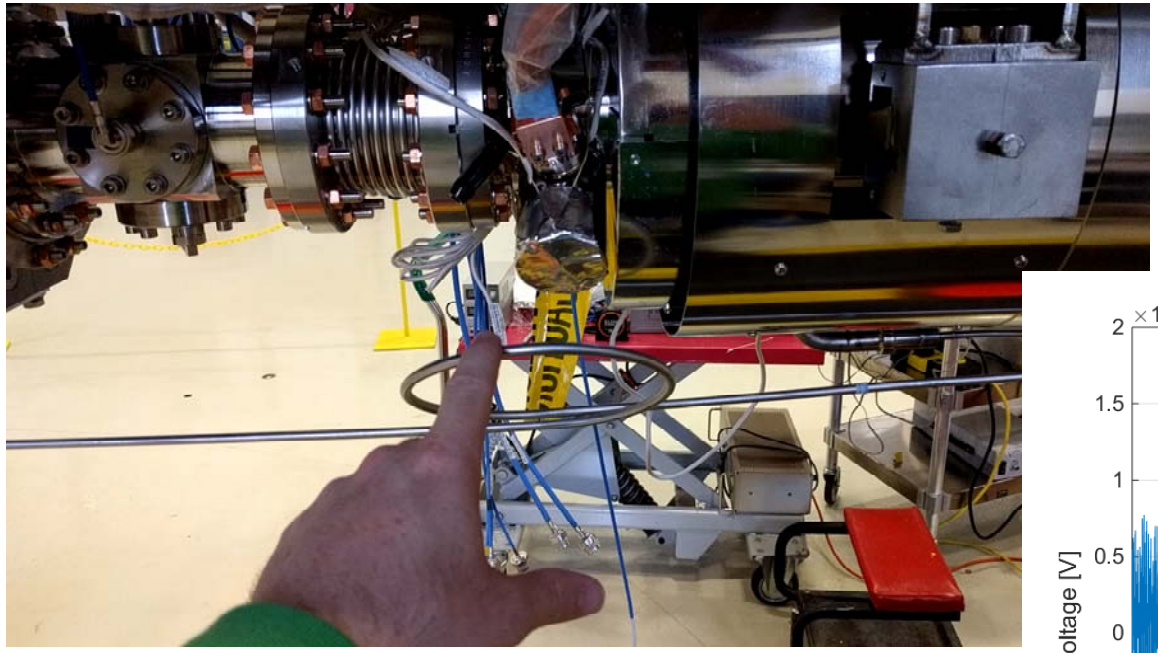
Support Pillar



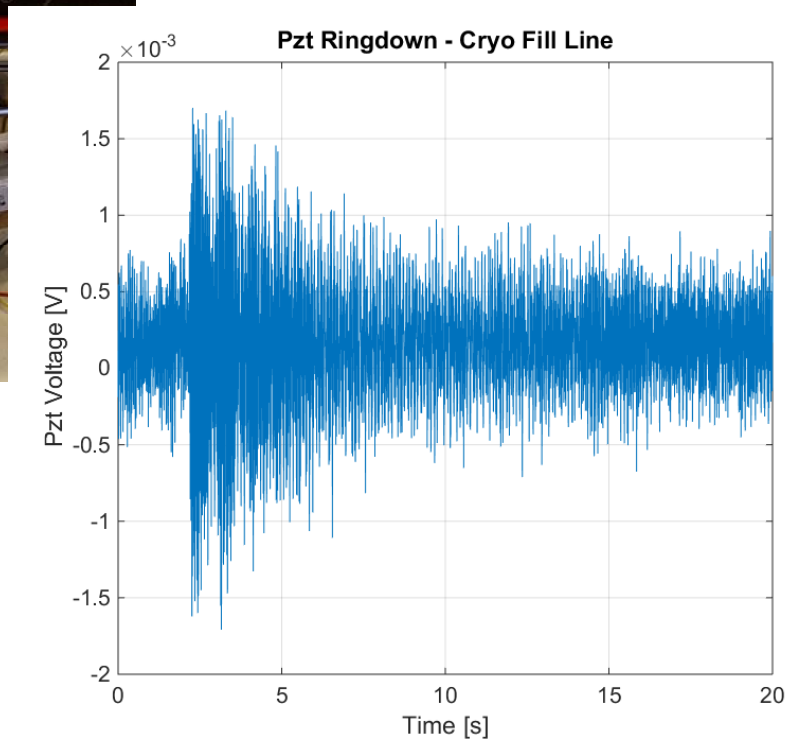


Highly surprising how far impulses traveled. Clear signals were visible even when striking the floor meters from the module.

Unsecured Cryo Fill Line

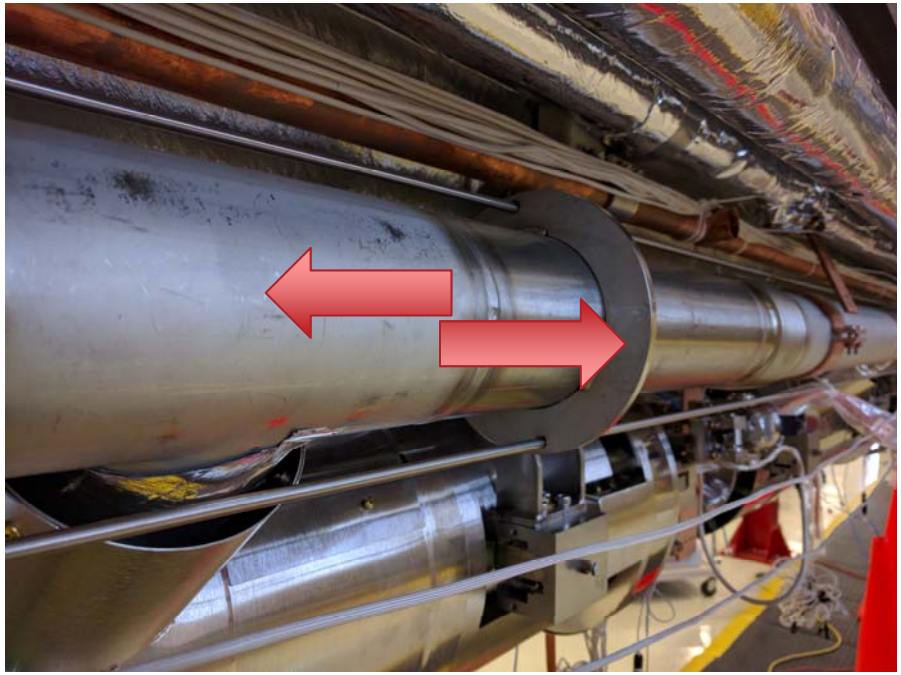


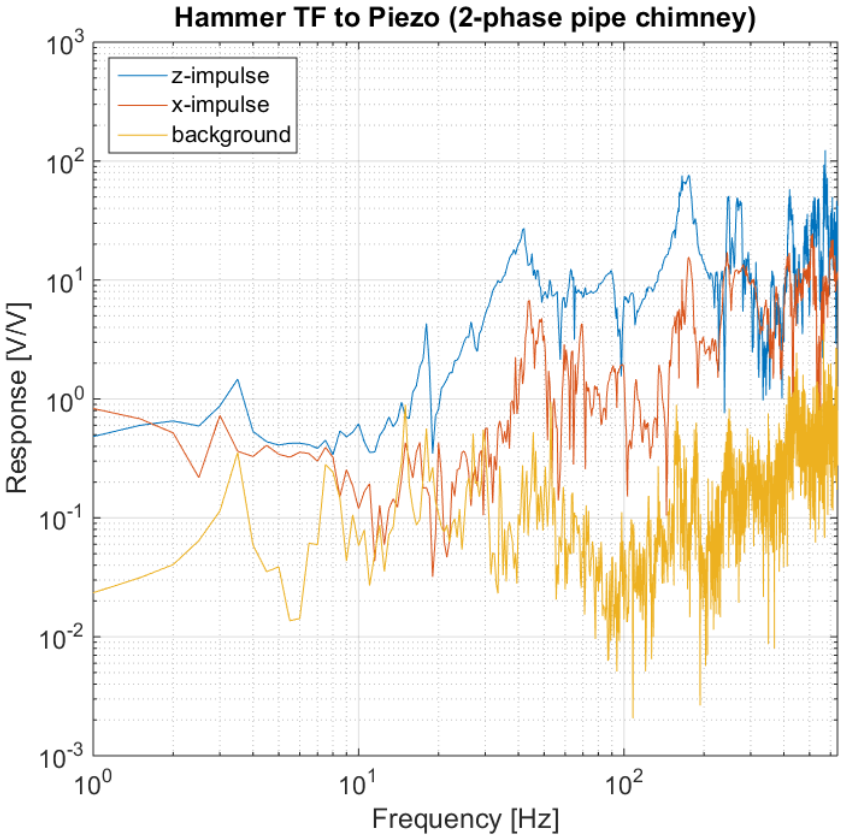
Very roughly:
~0.25 Hz Detuning



An unsecured cryogenic fill line was taught enough to have a very long tau. This was pointed out and secured. Each cavity has two of these.

Two-Phase Pipe Directional Impacts

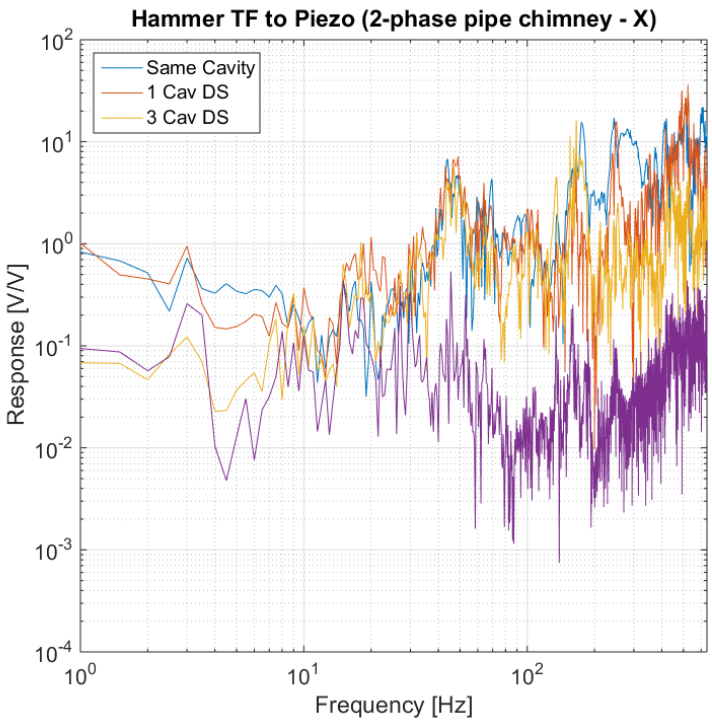


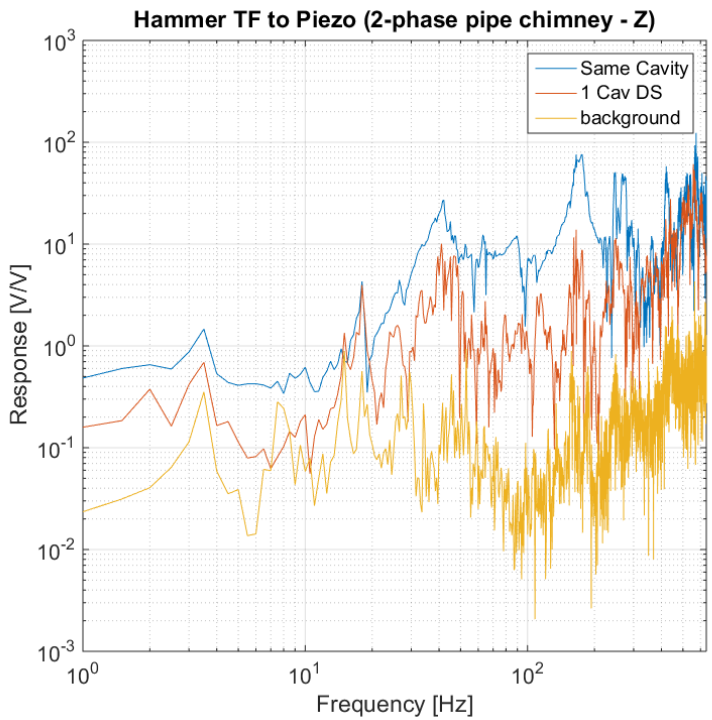


Impact on helium two-phase pipe in longitudinal and transverse directions. Clear reduced sensitivity of piezos to cavity transverse motion.

No real thought that cavity isn't responding, but transverse modes are less concerning.

Downstream Propagation

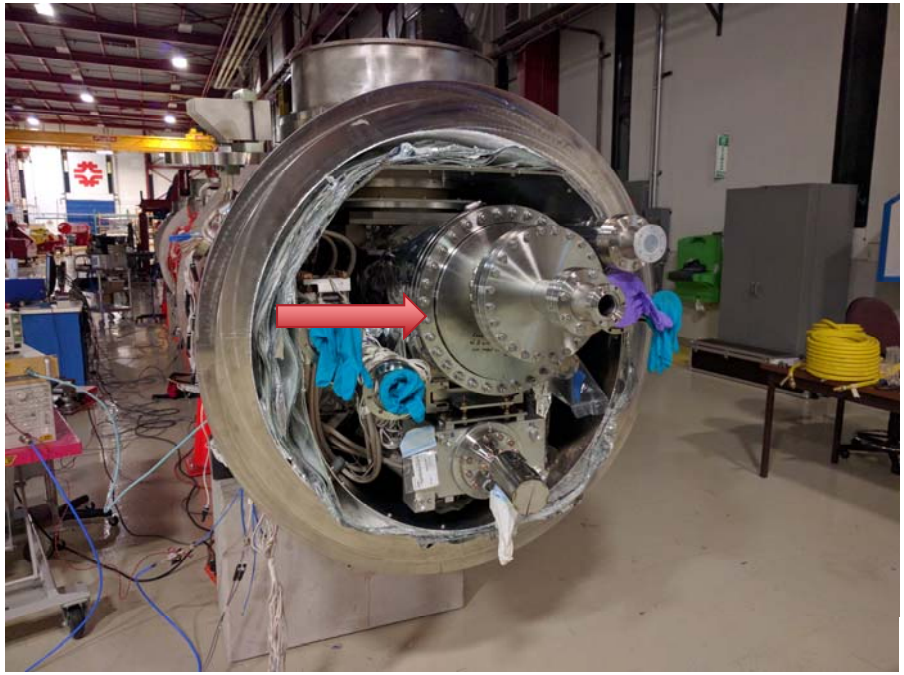


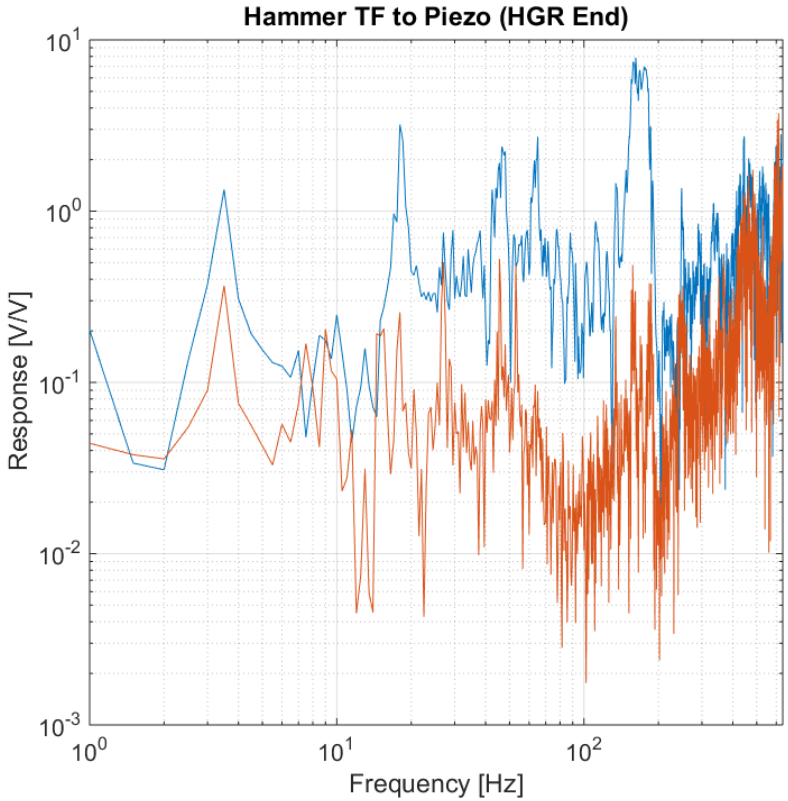


Impact on the two phase pipe at various points relative to Cavity 1.

Impact in Z further downstream does not translate directly to similar motion in Cavity 1.

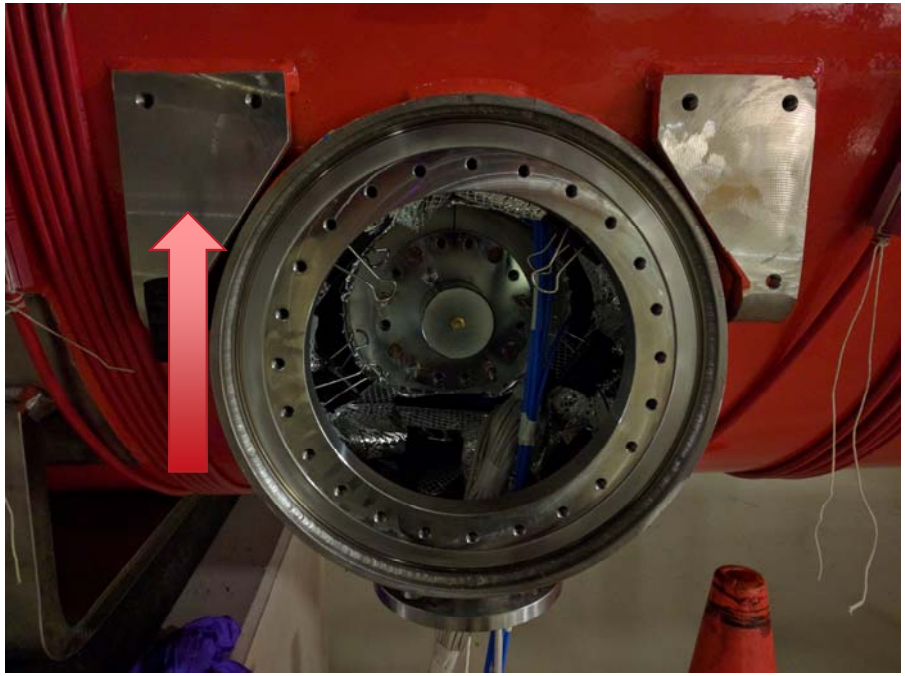
Helium Gas Return Pipe





As expected, impulse on the HGR pipe caused strong response in the cavity. One clear resonance at 9 Hz remains a mystery, but the ~180 Hz resonance is likely the cavity.

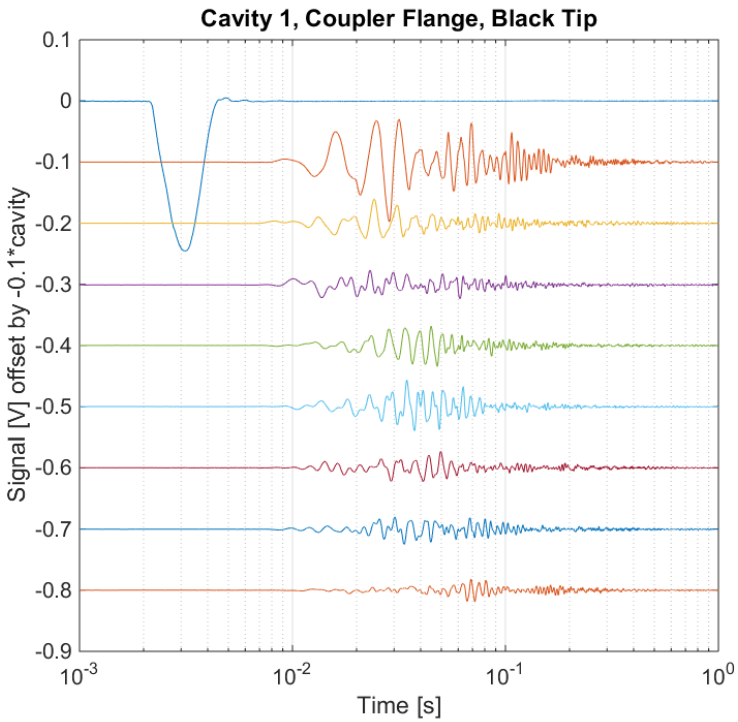
Cryo Vessel Testing

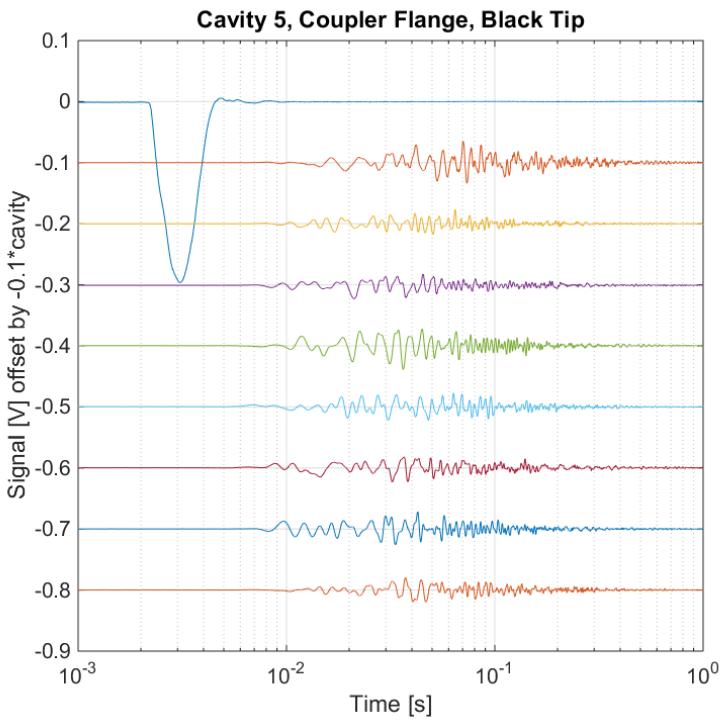


Once the string was installed in the cryo vessel, additional testing was done to see the whole string respond together.

Striking was done on the coupler attachment flats by Cavities 1 and 5. This gave the most repeatable striking surface.

Full Cryomodule Response

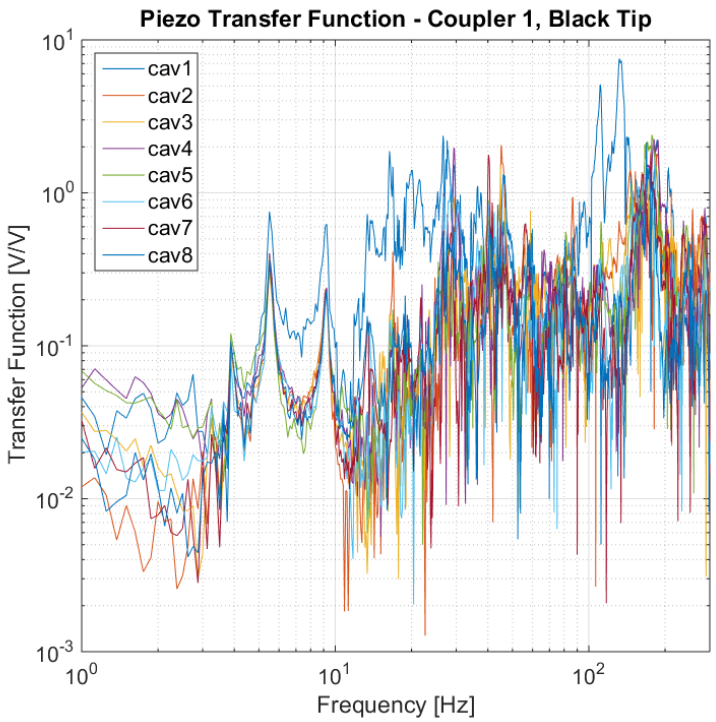


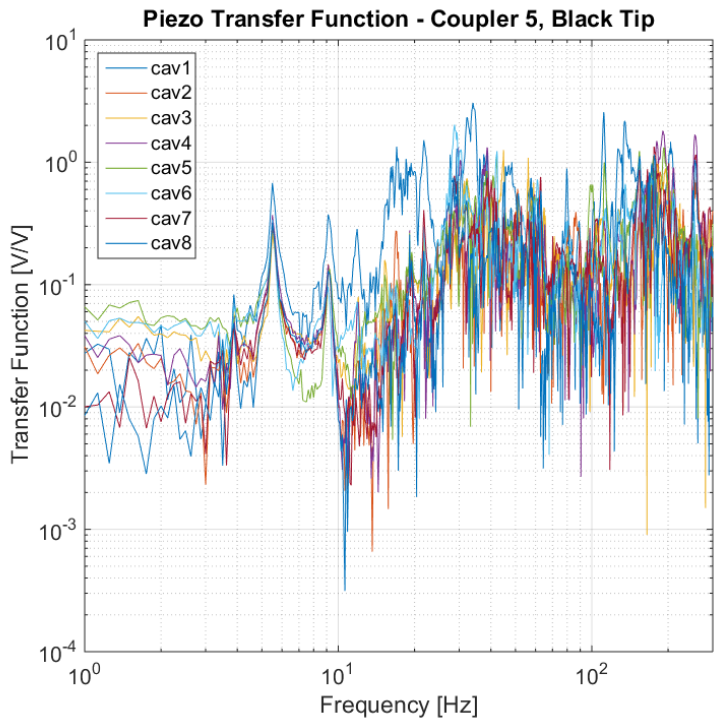


Once in the cryo vessel, all cavities were monitored simultaneously while striking various places on the vessel.

The propagation is evident in both plots, but the strong response of Cavity 1 is striking.

Coupler Flange Transfer Functions





Cavity 1 has a much stronger response than any cavity, even when the module is struck in the middle. Cavity 8 is anchored on the DS side with a small magnet, where Cavity 1 has a large gate valve on its US side.

Conclusions

- Impulse testing is a standard part of cryomodule design and testing, JLab has an extensive testing schedule for prototype cryomodules. They use it not only to prevent production problems, but as a knowledge base to rapidly diagnose and fix problems in operations.
- What has been shown in a first pass, revealing suspicious resonances that could be investigated in more detail.
- The XFEL-ish module that LCLS-II is using is a mostly mature design, especially the well-characterized 1.3 GHz cavities.
- Given the tight tolerances for PIP-II, and the new cavity designs being used (SSR, 650 elliptical), special attention is recommended to help avoid surprises.