CDF Silicon Detector

Wire-Bond Failures Induced by Resonant Vibrations

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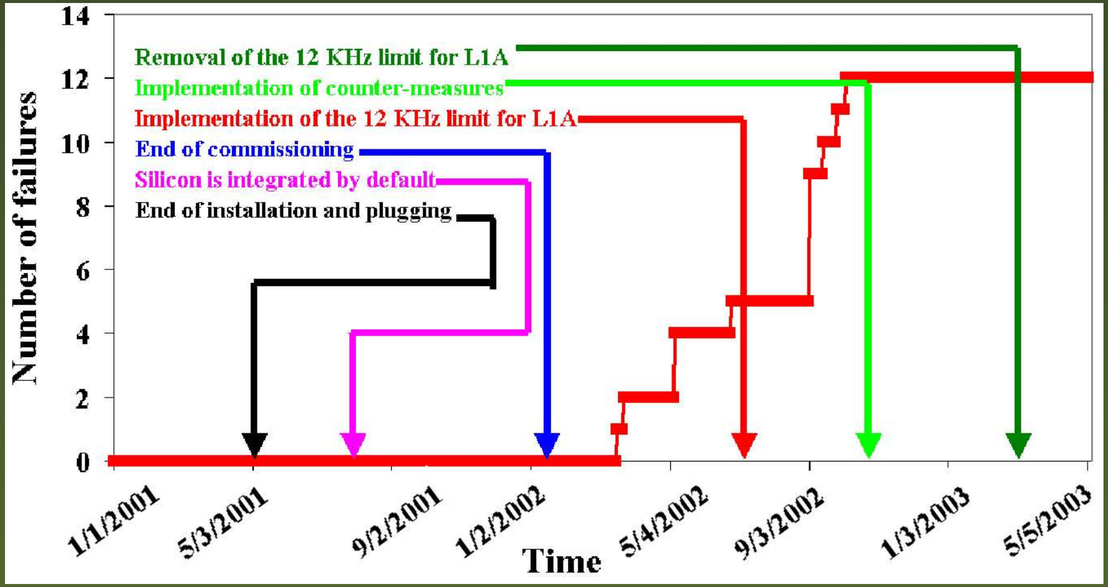
CDF Collaboration

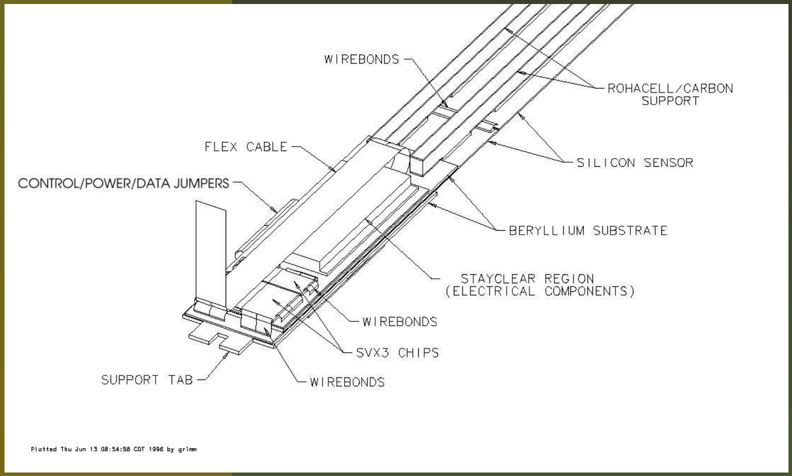
Component Failures

- After commissioning, Several failures occurred under anomalous trigger conditions.
- Two types of failures.
  - DVDD Jumper - loss of z information from detector
  - DOIM - loss of all information from the module
- Anomalous trigger conditions
  - “Torture Tests”: tests to explore dead-time at high rate.
  - high occupancy mode in SVX3 chips
- Both trigger conditions cause the system to be read-out at a fixed rate



DVDD Jumpers

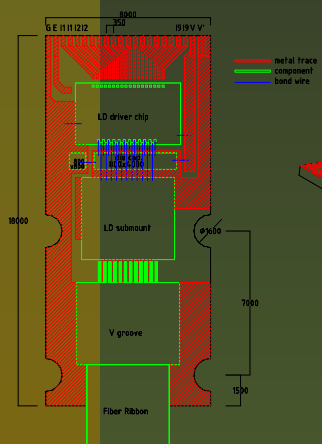
- Layers of SVX are double-sided w/ bonds connecting z to ϕ hybrids
- Bonds supply power and move data from z channels during readout.
- Bonds are in a plane orthogonal to the magnetic field in CDF.

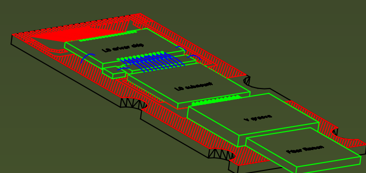


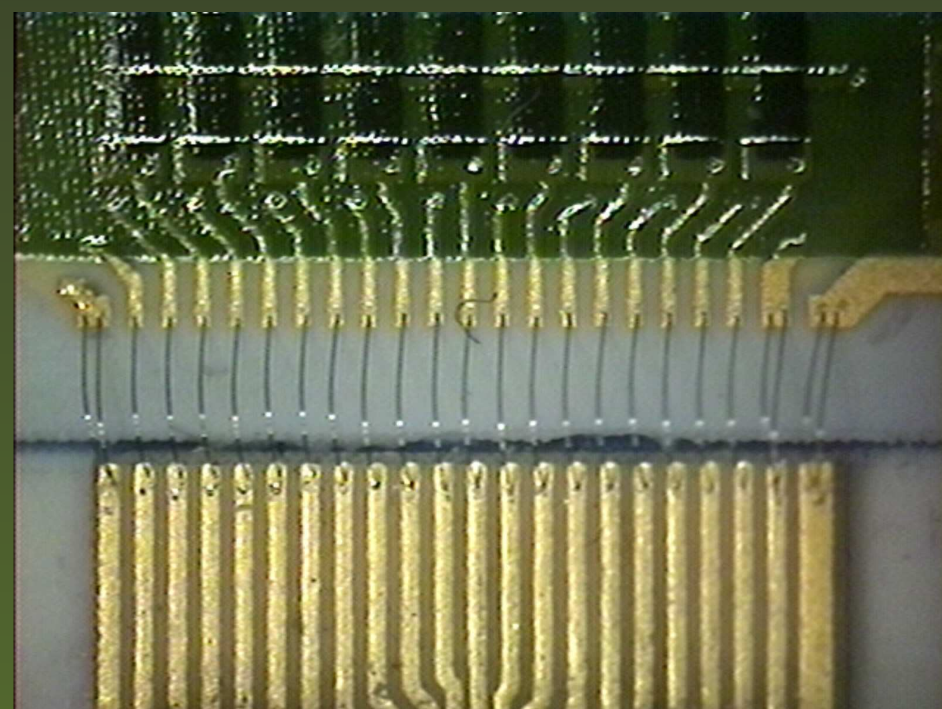
DOIMs

Dense Optical Interface Module

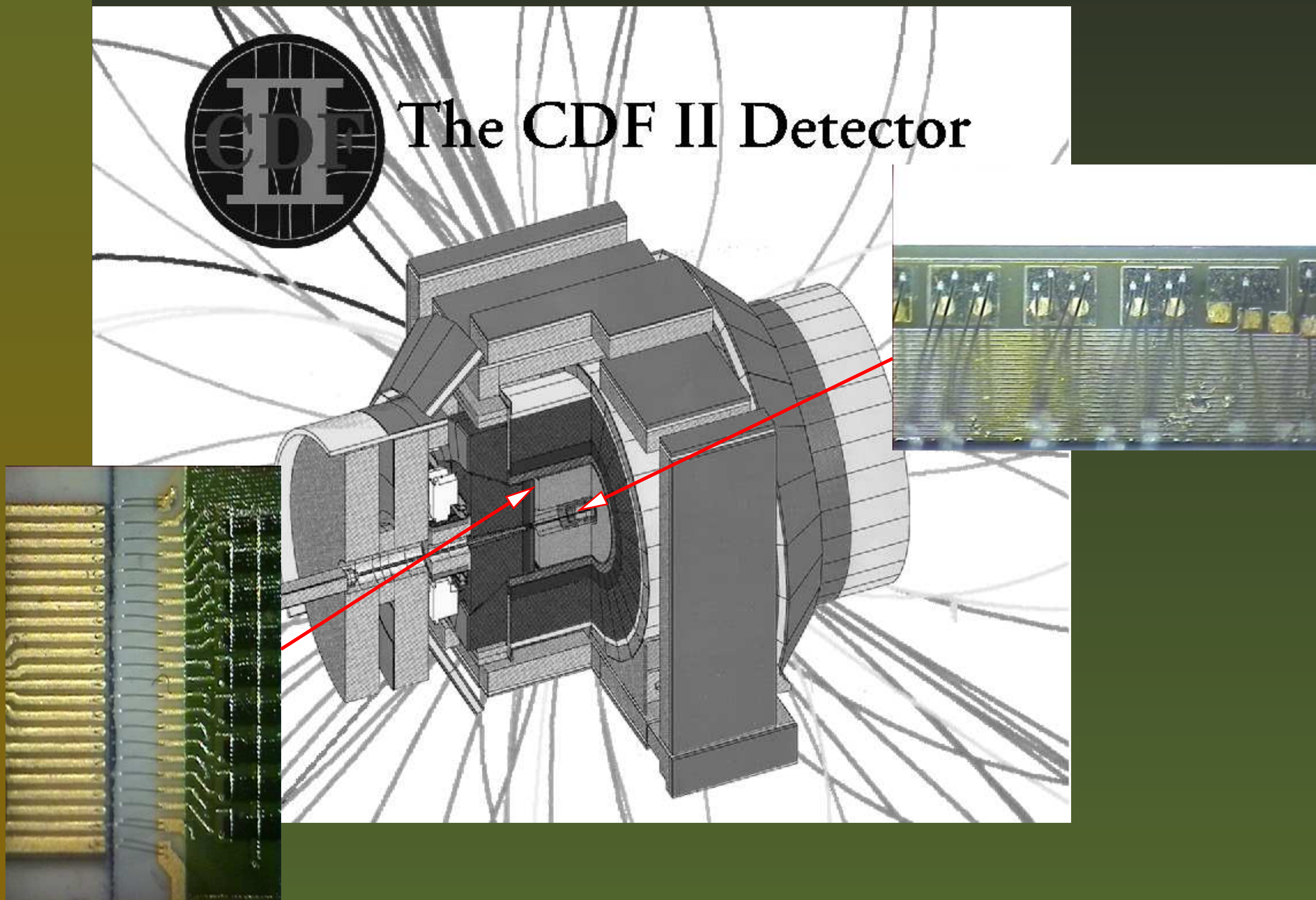
- Laser diode package that moves data from detector to VME crates in parallel (9-bit bus).
- Power connection wire-bonds are in a plane parallel to magnetic field.
- Vertical components however are perpendicular to magnetic field.





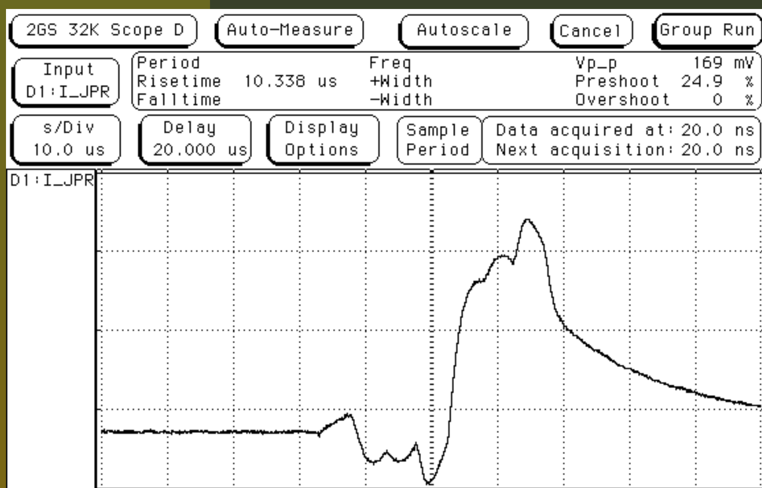


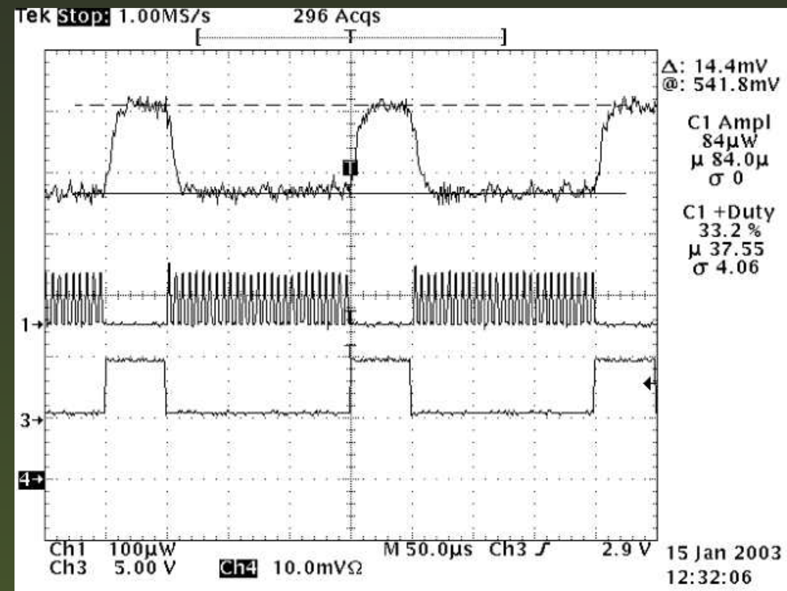
The CDF Detector



DOIM and Jumper Currents

- DVDD Jumpers have ΔI up to 150mA
- I_{max} occurs when readout shifts from ϕ to z chips

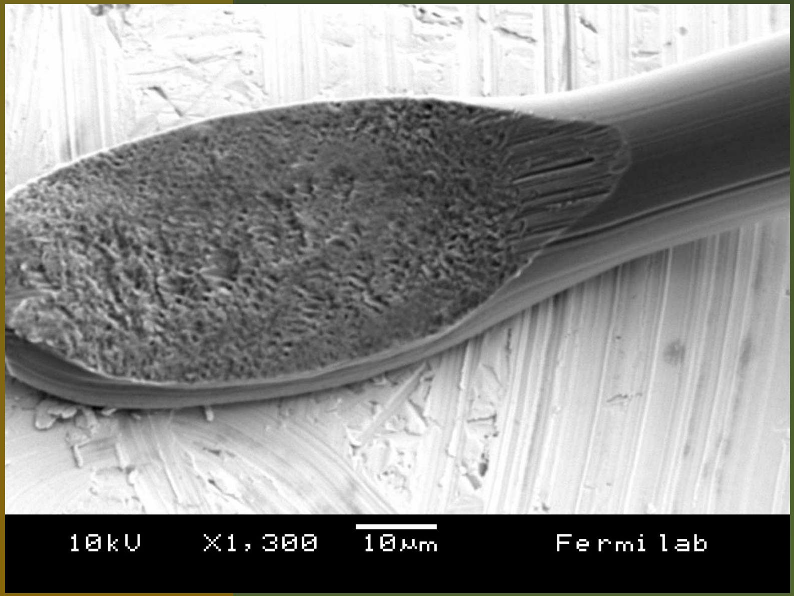


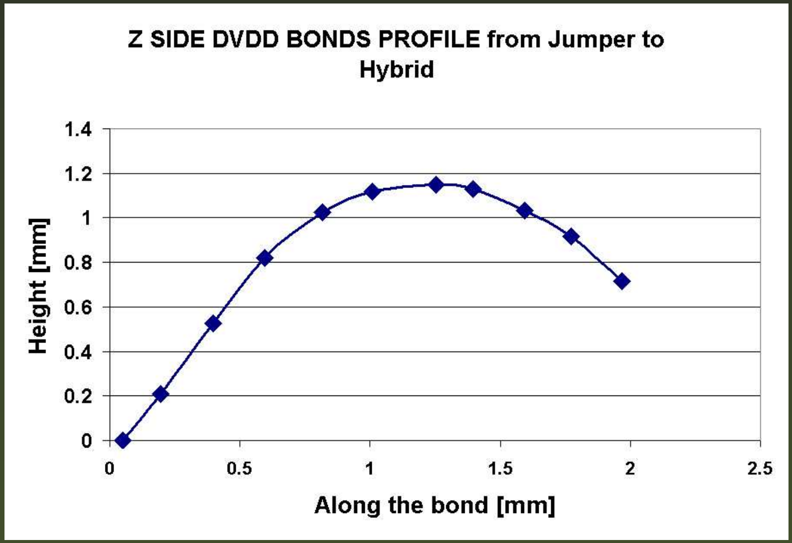


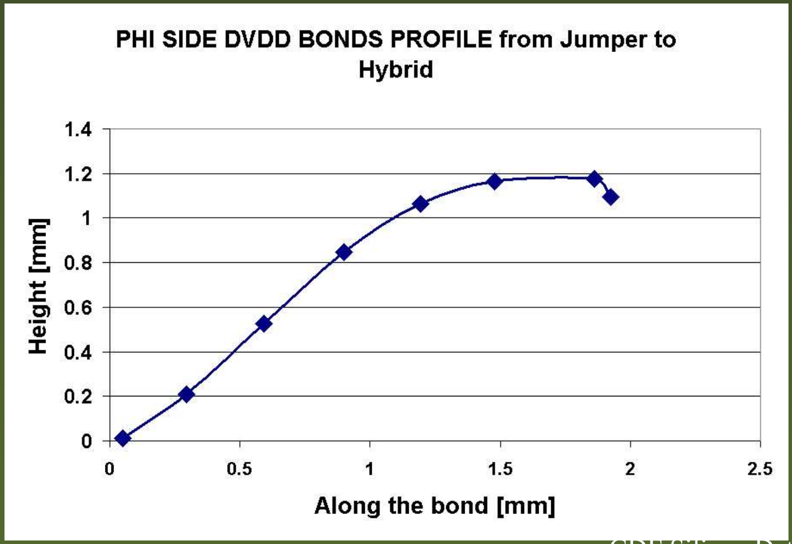
- DOIMs have ΔI of no more than 40-50mA (top trace)
- Current swings come from switching between laser diode and dummy loads

Bond Specifications

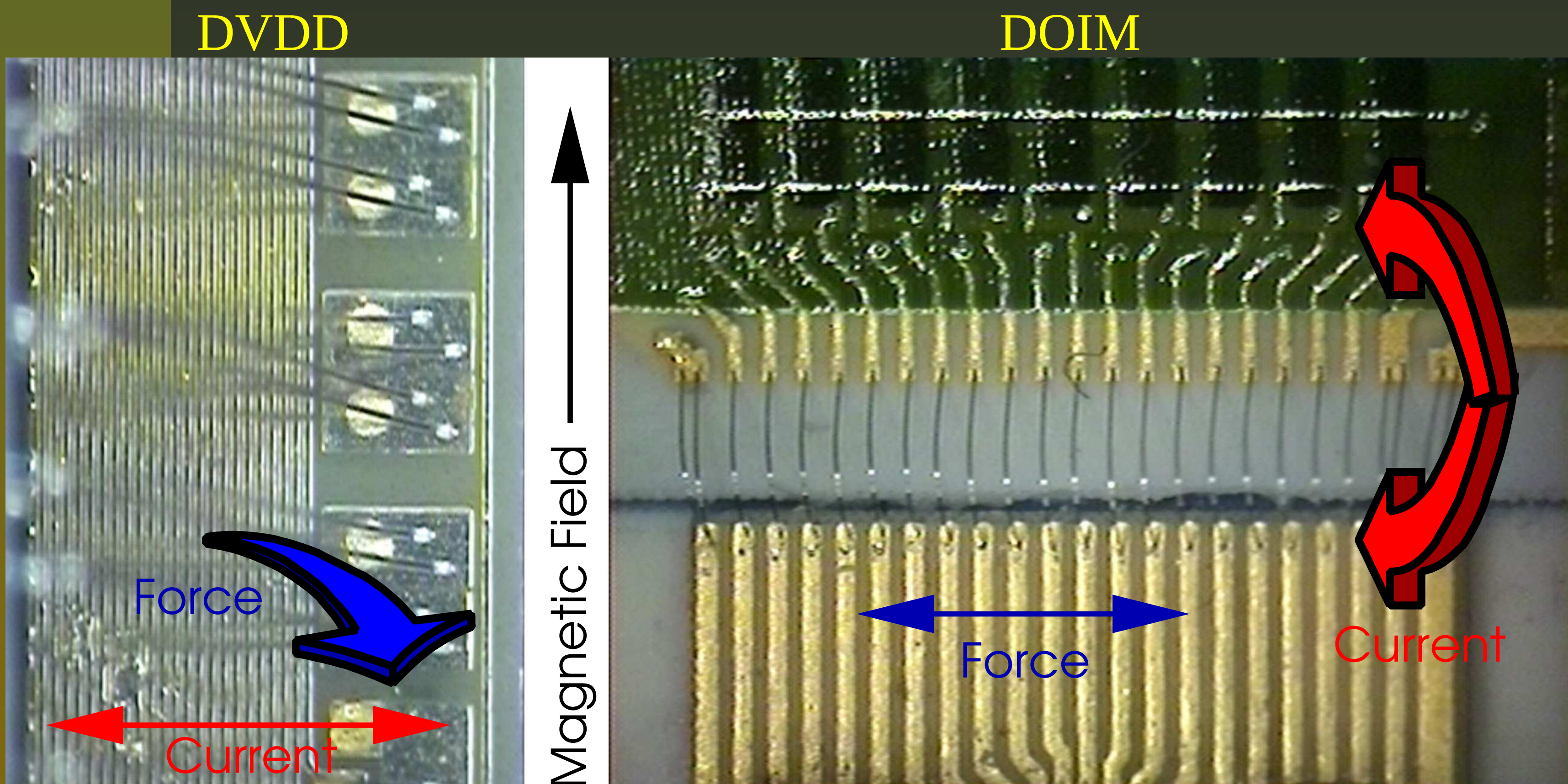
- $\sim 2mm$ in length
- $\sim 25\mu m$ in diameter
- Composition: 99% Al 1% Si
- Different profiles for DOIM, ϕ and z-side bonds
- Not encapsulated







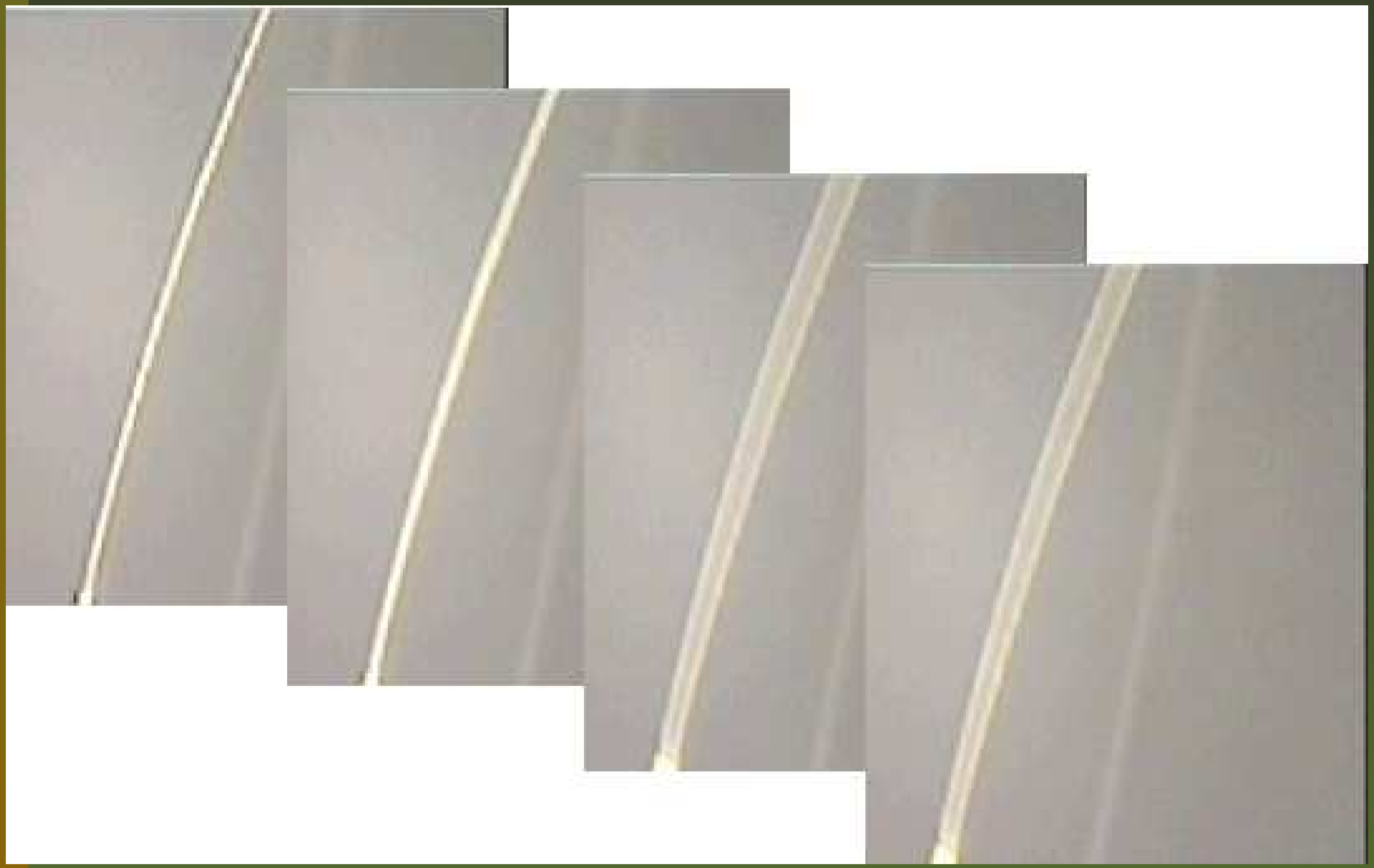
Lorentz Forces



$$|F_{lorentz}| = IBl \approx .2A \times 1.4T \times .002m = 5.6 \times 10^{-4} Nt$$

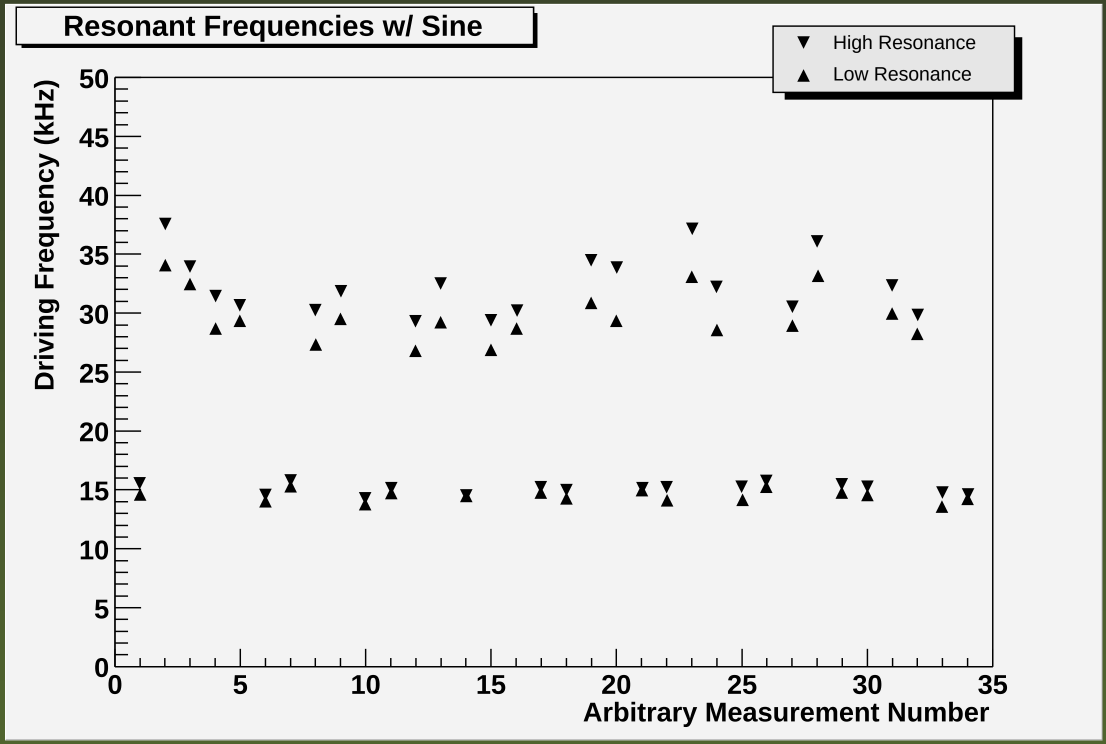
Resonance

- Resonance enhances fatigue due to Lorentz forces
- Visually scanned for resonance in bonds in a 1.4T test magnet
- Resonances observed with driving currents of 10mA - 150mA.



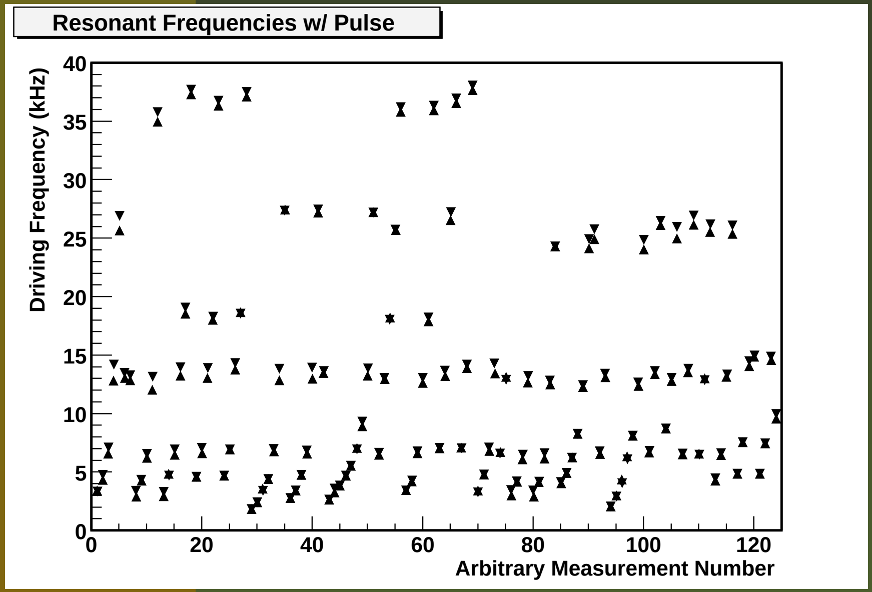
Characteristic Frequency

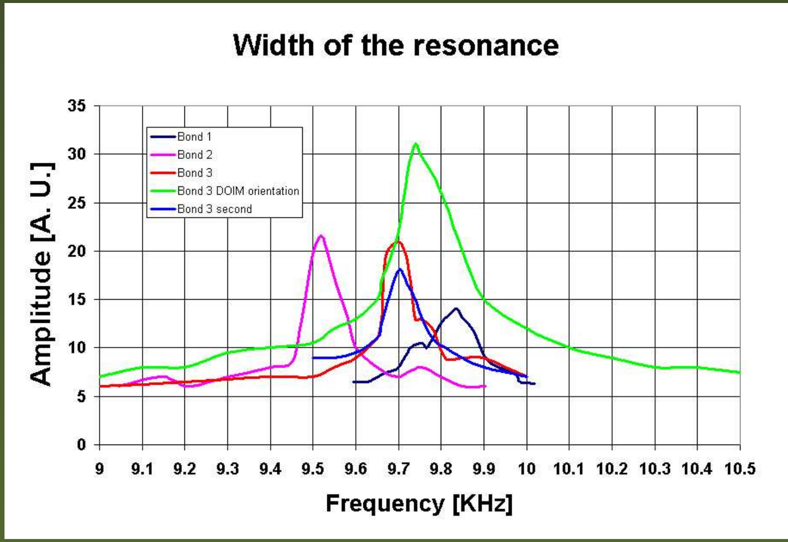
- Initial calculations for 2mm SiAl bond predicted 15kHz
- Many bonds tested w/ 40mA sinusoidal driving current (push and pull)
- Fundamental frequency in agreement with calculations
- 1st harmonic was also observed
- Typically 1kHz resonant width



More Realistic Currents

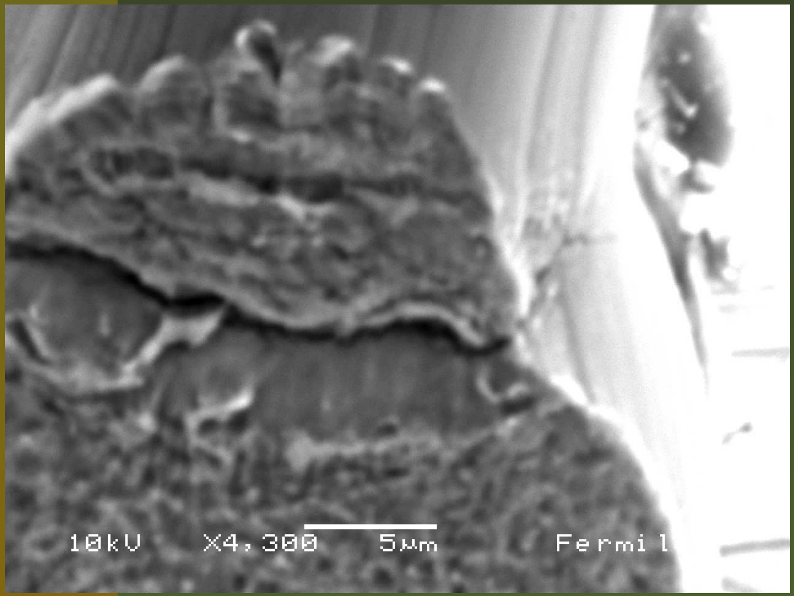
- Bonds driven with a more realistic current pulse (100mA, $15\mu S$) exhibit more resonances.
- Resonant frequency f can be excited with pulses at f, $f/2$, $f/4$, etc
- Width of resonance is between 1 and 200Hz.
- Differently shaped bonds imply different frequencies.

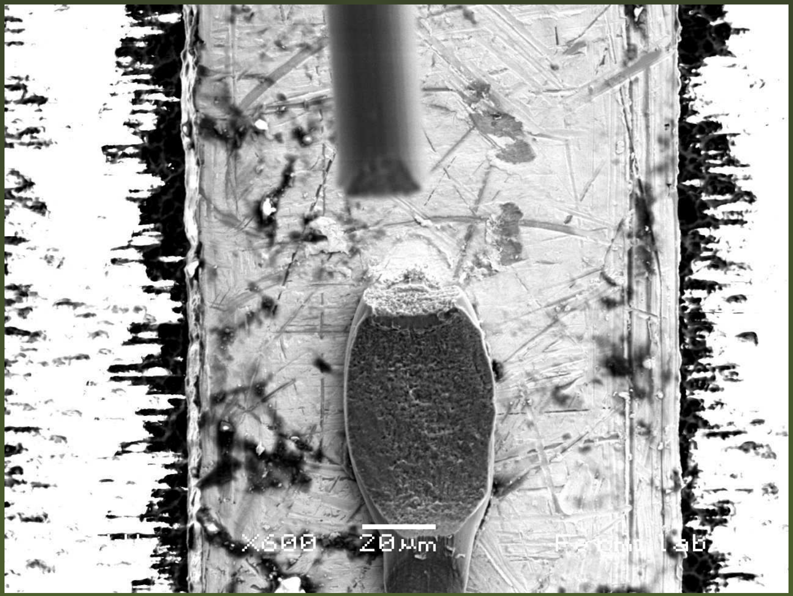




Foot Fatigue

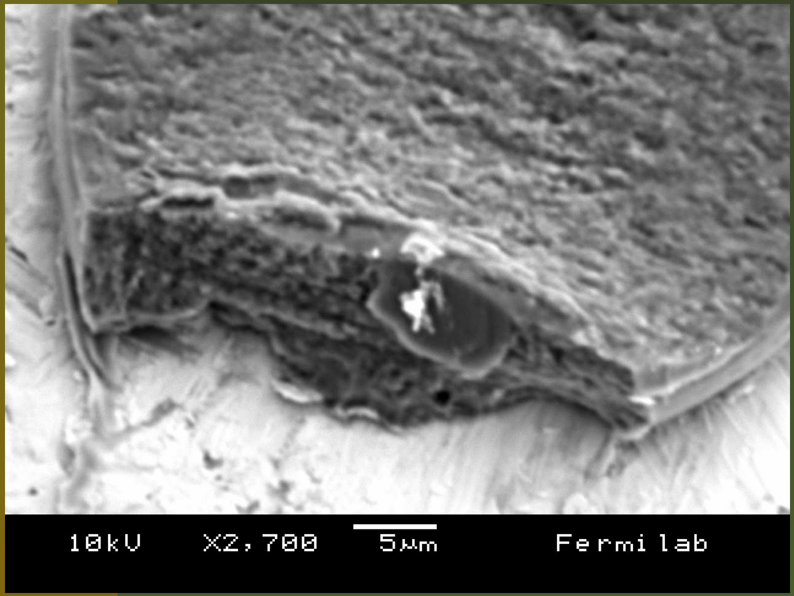
- On the time-scale of minutes, a resonating bond will fail
- At 10kHz this is about $10^5 - 10^6$ cycles.
- Breakage occurs at the bond's foot
- Breakage is due to stress fracture that forms during vibration



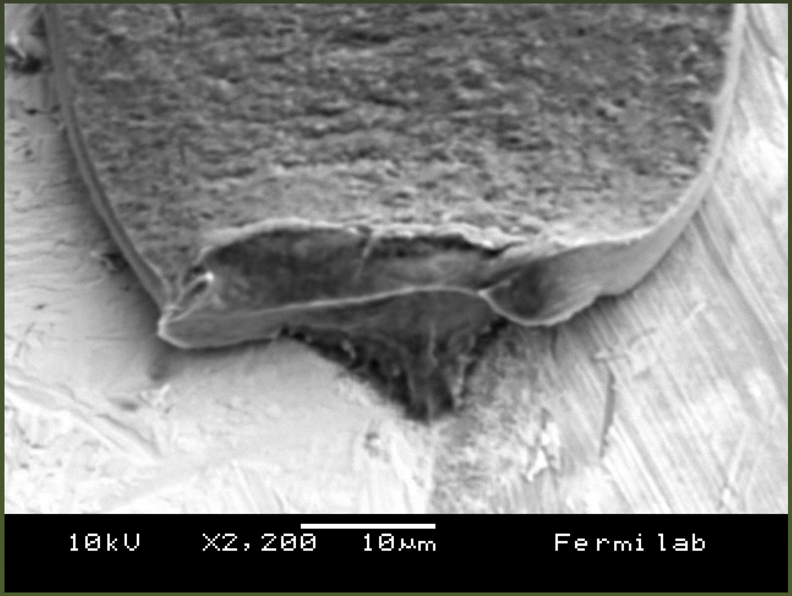


Fatigue vs. Pulling

- Failure due to fatigue looks very different from a pulled bond
- Similar to a failure mechanism described in a paper by Raymond T. Fitzsimmons and C. E. Miller (IEEE Transaction on Components, Hybrids and Manufacturing Technology, Vol. 14, No. 4, December 1991)



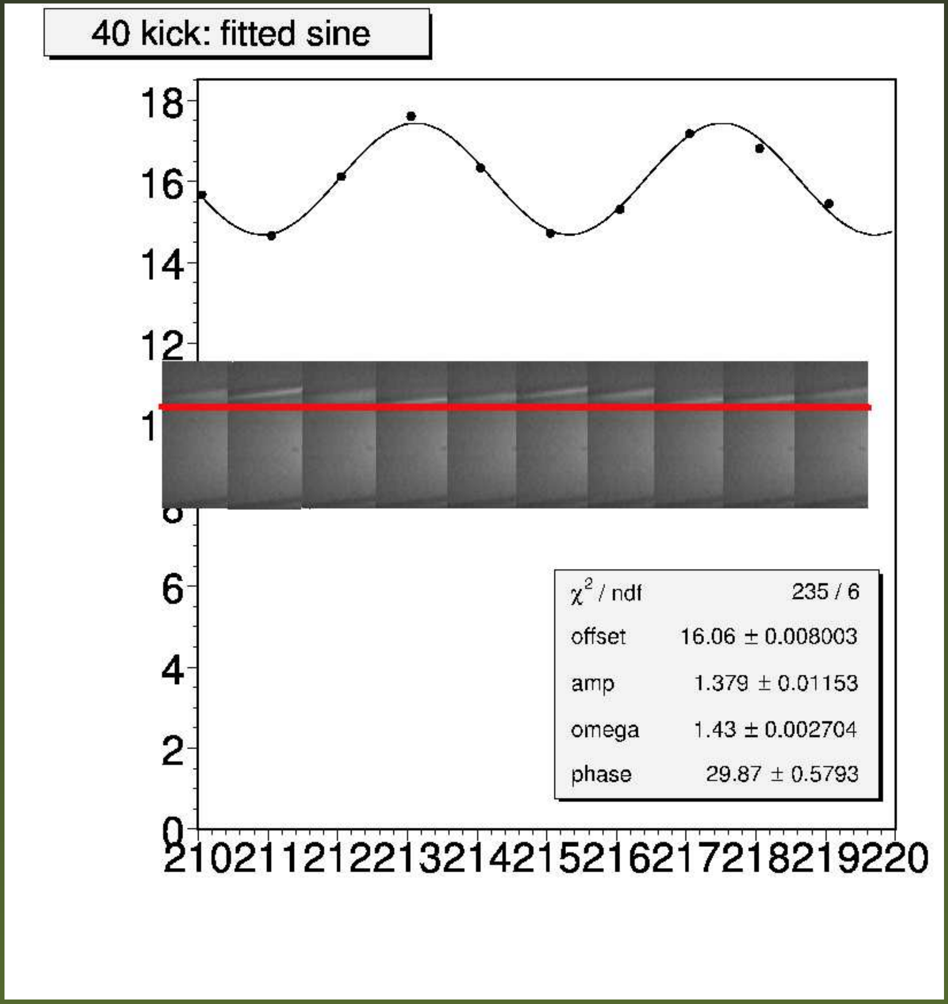
Fatigue Failure



Pull Failure

Fast Video Analysis

- A camera with a 40500Hz shutter rate was used to record the motion of bonds.
- Single frames have been digitized and a quantitative analysis performed

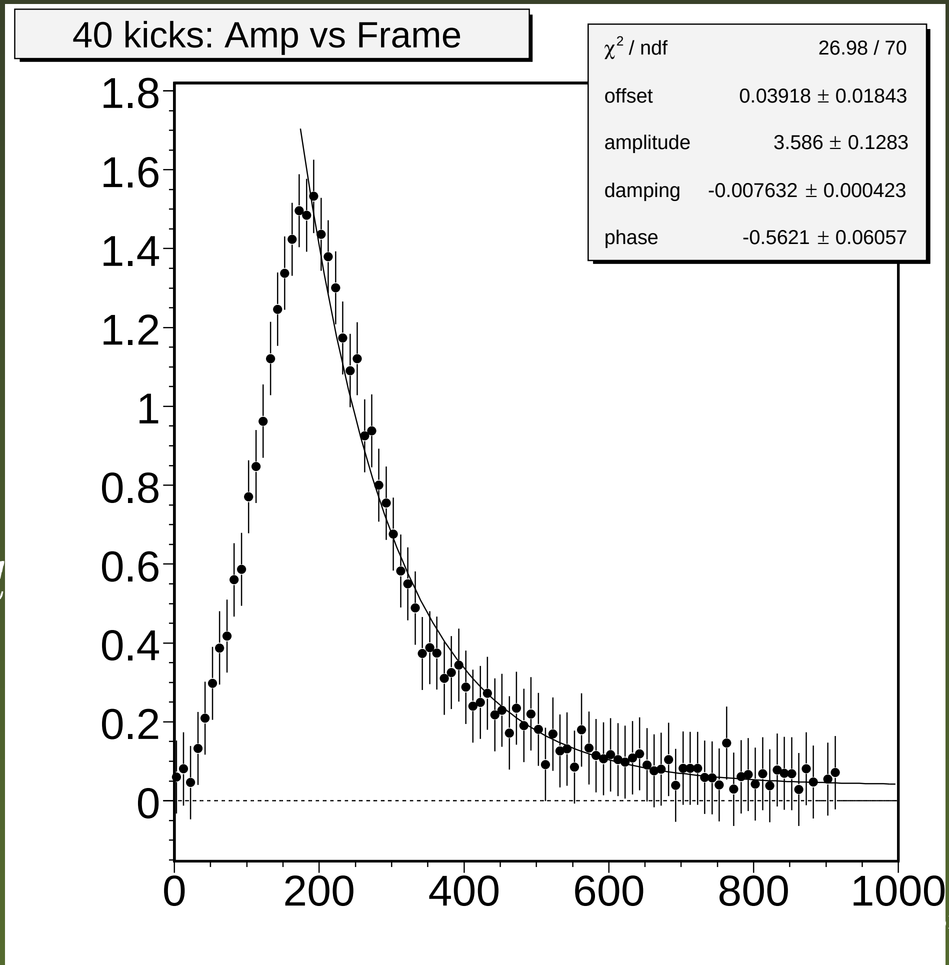


Excitation and Damping

- Bonds were excited w/ a limited number of $16\mu S$, $75mA$ current pulses
- The amplitude was measured as a function of the number of pulses
- The damping ratio was also measured from the decay of the free oscillations to be roughly 0.01

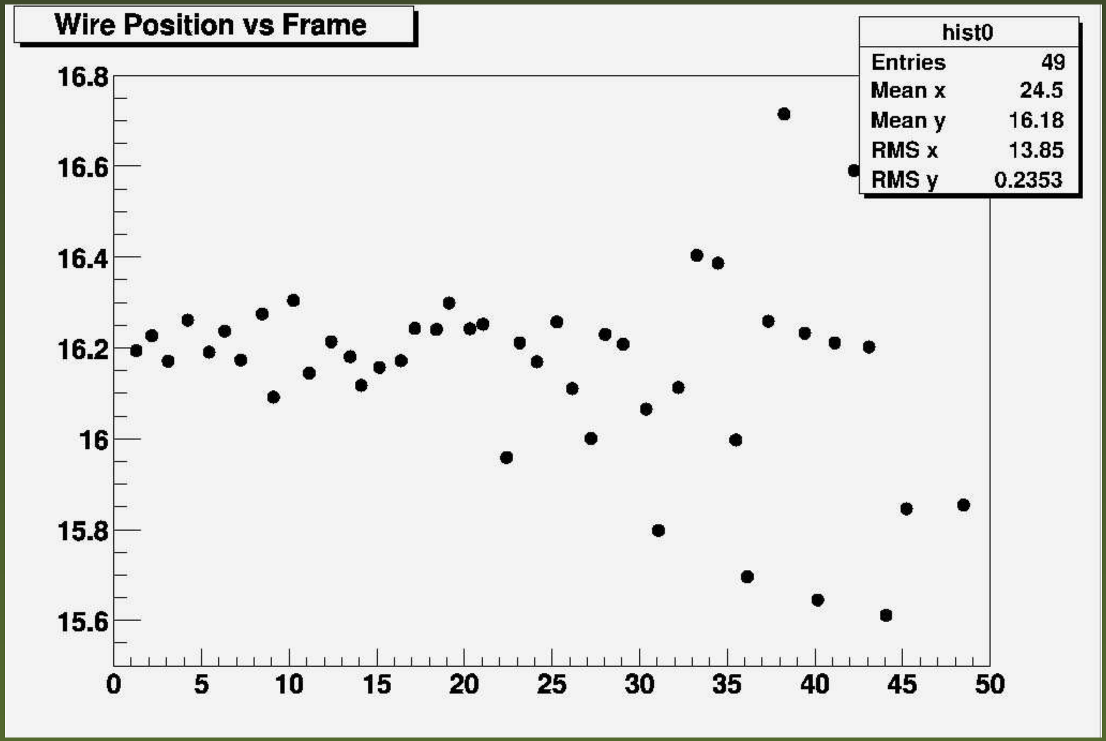
Free Oscillation

$$y = A + Be^{cx-d}$$



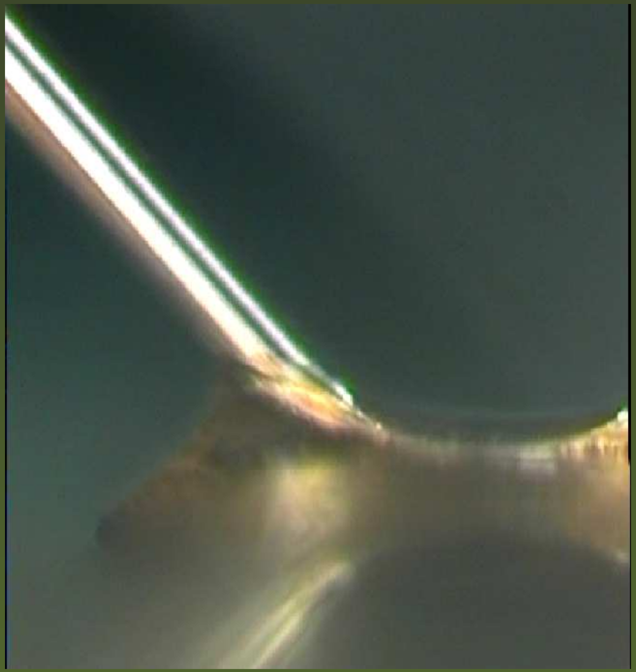
Mitigation

- 3-4 current pulses at the bond's characteristic frequency are enough to excite motion.
- Efforts have been made to reduce Lorentz forces.
  - Reduce current swings by changing SVX3 chip settings
  - Reduce duration by lowering noise occupancy
- Minimize time at resonance; trigger inhibit on resonances detected directly with FFT.
- Banned "Torture Tests"



Encapsulation

- The foot of the bond was encapsulated w/ Sylgard 186 Silicon Elastomer
- Encapsulant thickness is no more than $50\mu m$
- Amplitude of resonant vibrations was reduced by more than an order of magnitude
- Unable to break encapsulated bonds even when driving for several hours with large currents ($\sim 500mA$)



Conclusion

- Last fall the CDF experiment faced a crisis due to internal unrecoverable failures on the silicon detector
- The source of the problem has been understood to be a simple physics mechanism
- The understanding of this problem should be applied to the construction of future silicon detectors
- Counter measures have been studied and applied to the CDF experiment. Since the implementation, no other failures have occurred
- Resonance cannot be avoided but the accumulated stress and fatigue on bonds has been minimized by
  - Reducing the strength of the Lorentz force
  - Reducing the time spent at resonance
- An encapsulation method for future applications has been successfully tested on a small number of samples