Second Sound as a Cavity Diagnostic Tool

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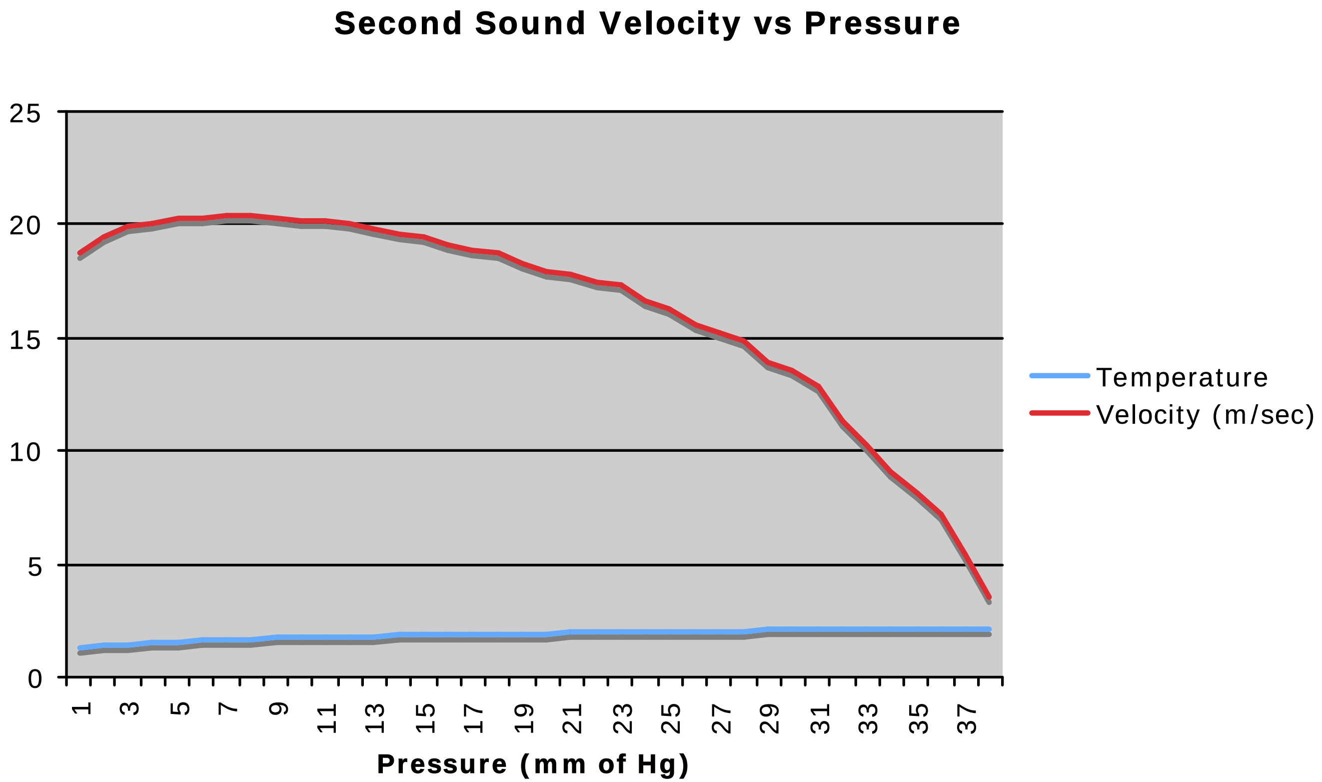
- Properties of Liquid Helium
- Transducers to Detect Second Sound
- First Multi-cell Tests
- Single Cell Tests
- Future Developments and Conclusions

Liquid Helium Properties

- Wave propagation in liquid helium
- Normal density wave = First Sound
- Below the Lambda Point a temperature wave can propagate (= change in the ratio of superfluid to normal fluid) = Second Sound
- Density wave in superfluid = Fourth Sound
- Velocities are ~ 300 m/sec, ~ 20 m/sec, and ~ 300 m/sec respectively
- Velocity of Second Sound is temperature dependent
- Attenuation of Second Sound is also temperature dependent especially near the Lambda Point

Liquid Helium Properties

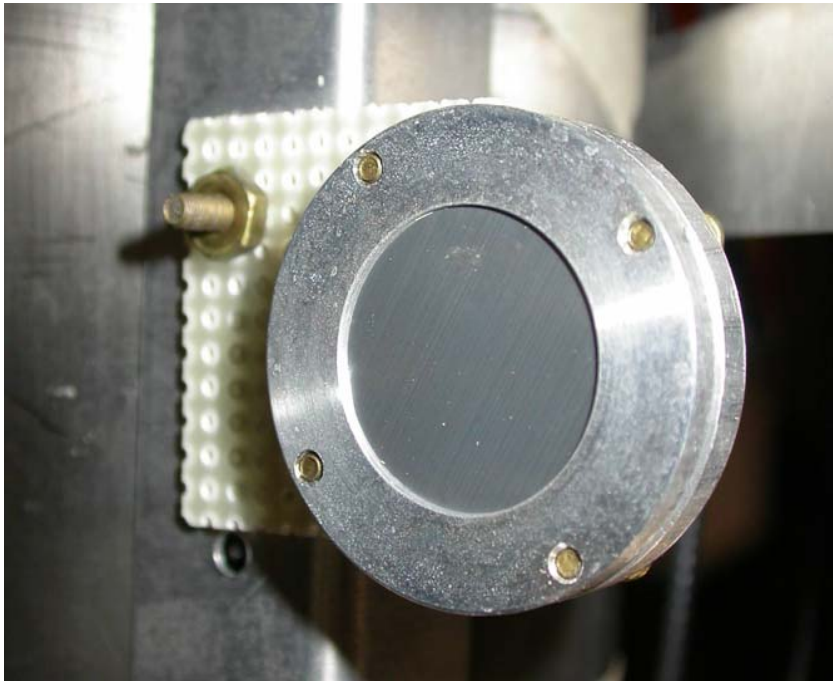


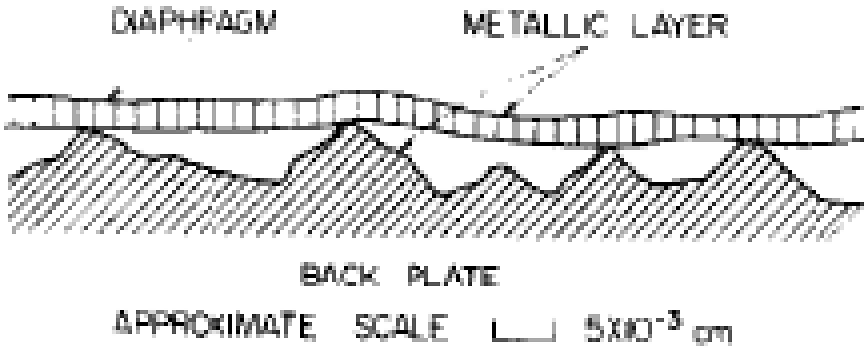
Second Sound Detection

- Resistors with large temperature coefficients can be used
- Oscillating Superleak Transducers (OST) sense only Second Sound and provide a much more sensitive and selective detector in noisy environments (see R. A. Sherlock and D. O. Edwards, "Oscillating Superleak Second Sound Transducers" Rev. Sci. Instrum. 41, Pg. 1603 (1970))
- Response time can be in the range of 0.1 msec or less which implies a spatial uncertainty of ~ 2 mm if the start time can be determined to this same timing uncertainty.

Second Sound Detection

- Oscillating superleak transducers used to detect second sound waves (shown on the right)
- Operation is analogous to a Helmholtz resonator
- Typical tests use 8 transducers to locate the location of defects

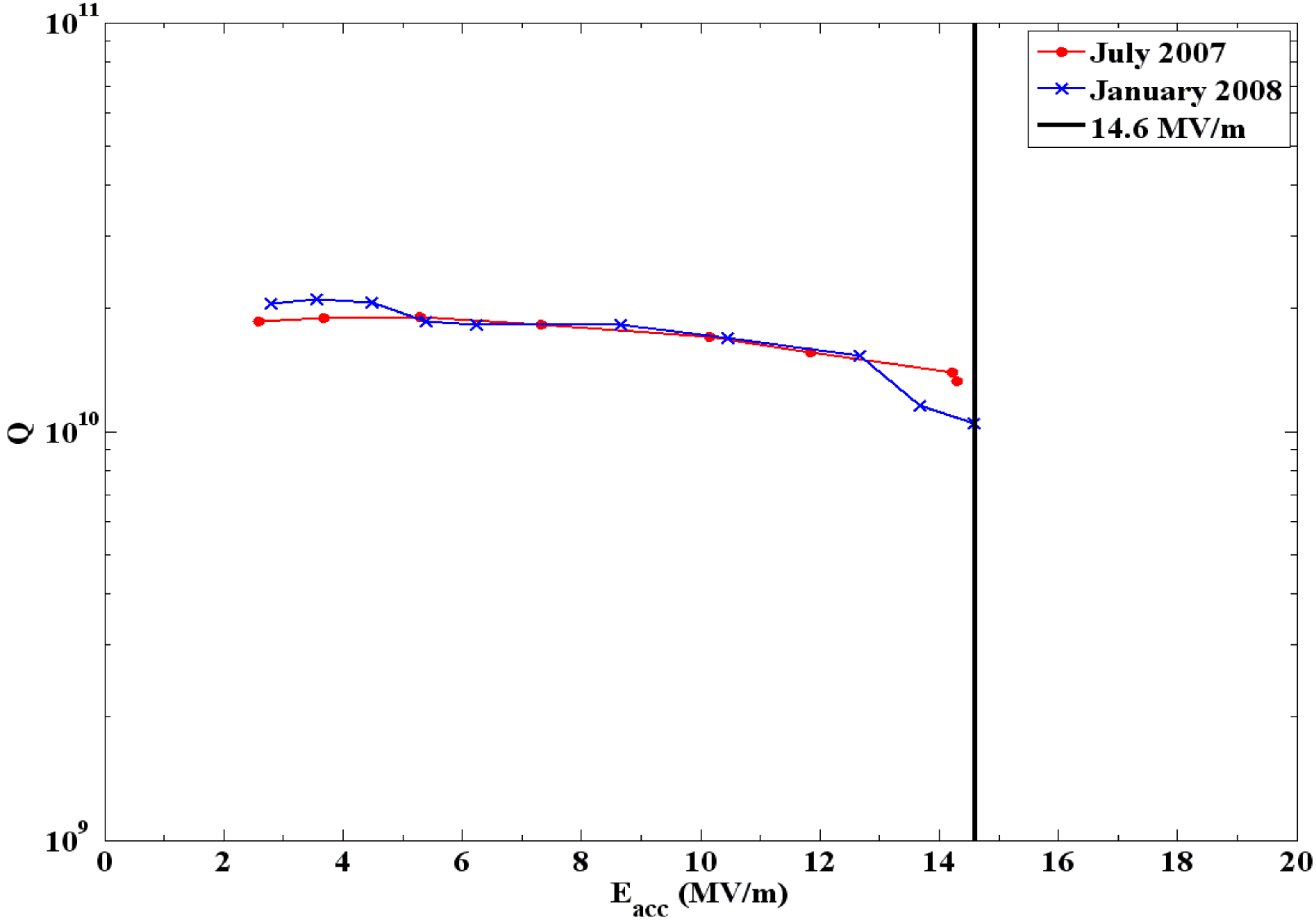




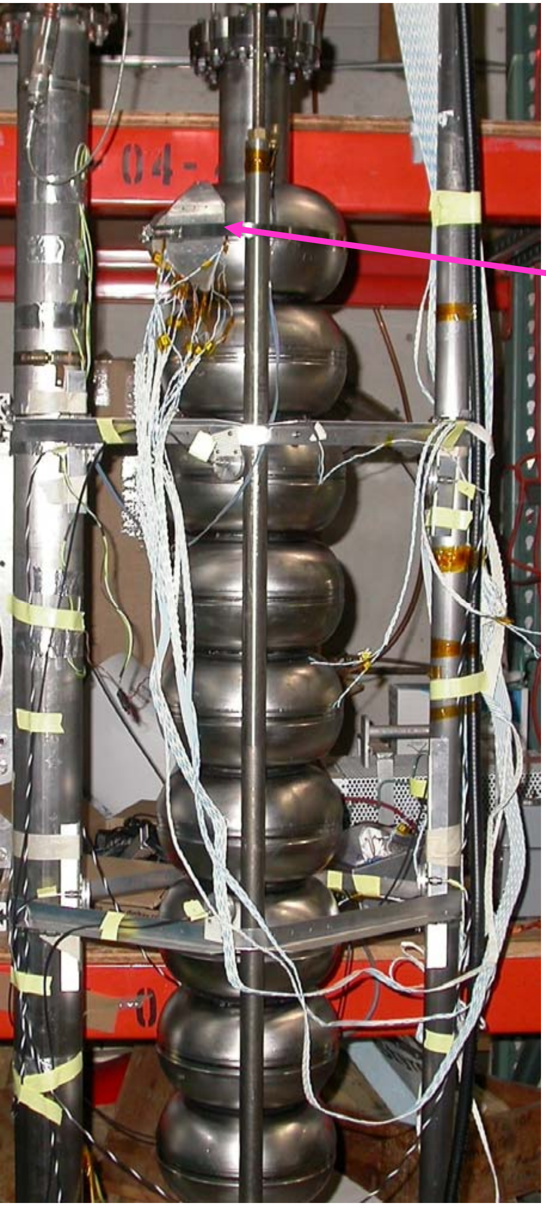
Multi-cell Cavity Tests

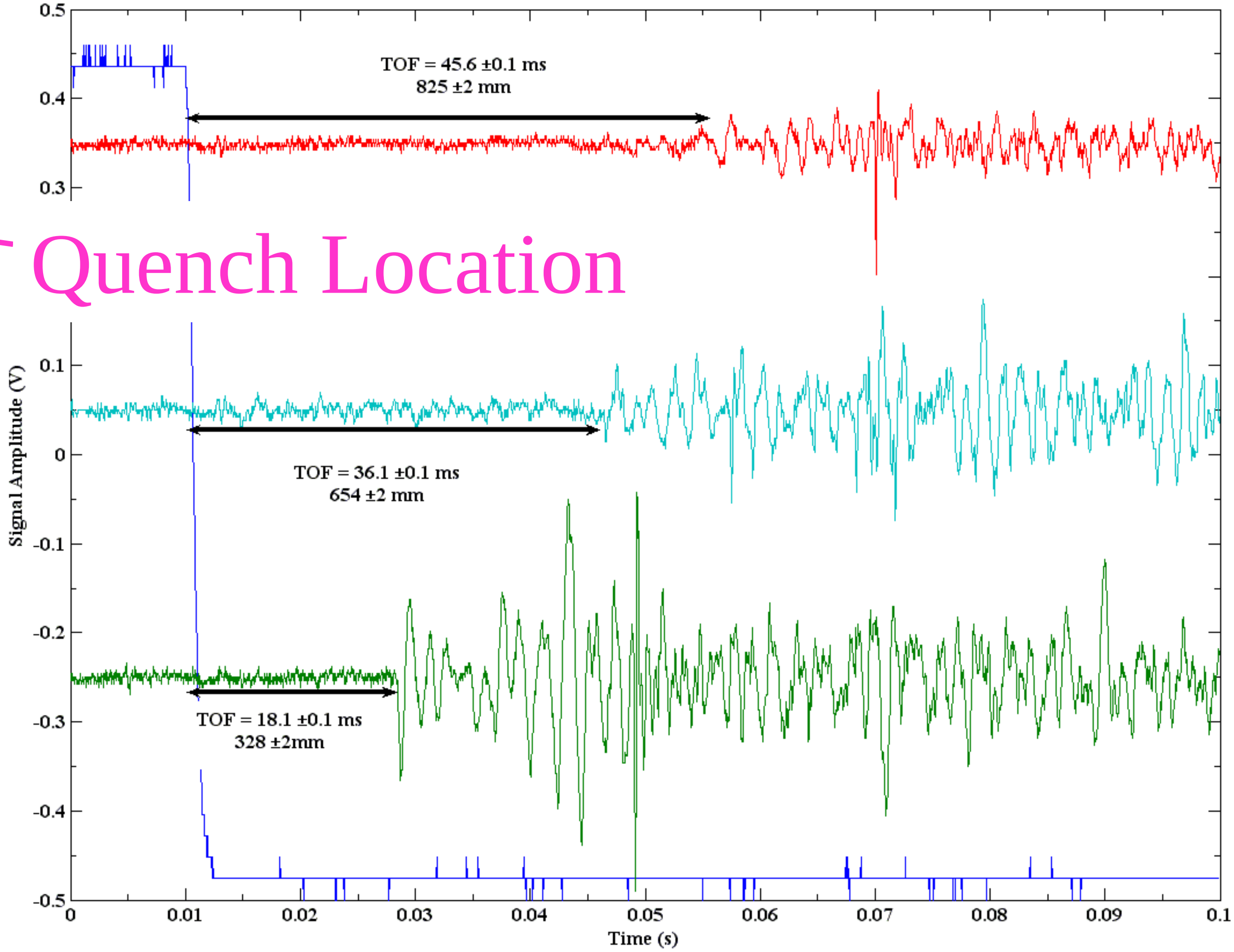
- Tests of nine cell cavity manufactured by AES
- Cell geometry is based on the re-entrant design that holds the record accelerating gradient (59 MV/m accelerating) for single cell cavity
- First test was without OSTs
- Second test with 8 OSTs but one signal cable opened on cool down
- During the third test the Type N connector on the input coupler failed - not able to get enough power into the cavity to cause a quench but did get the resistor thermometer data

First Successful Use of OSTs to Locate Quench



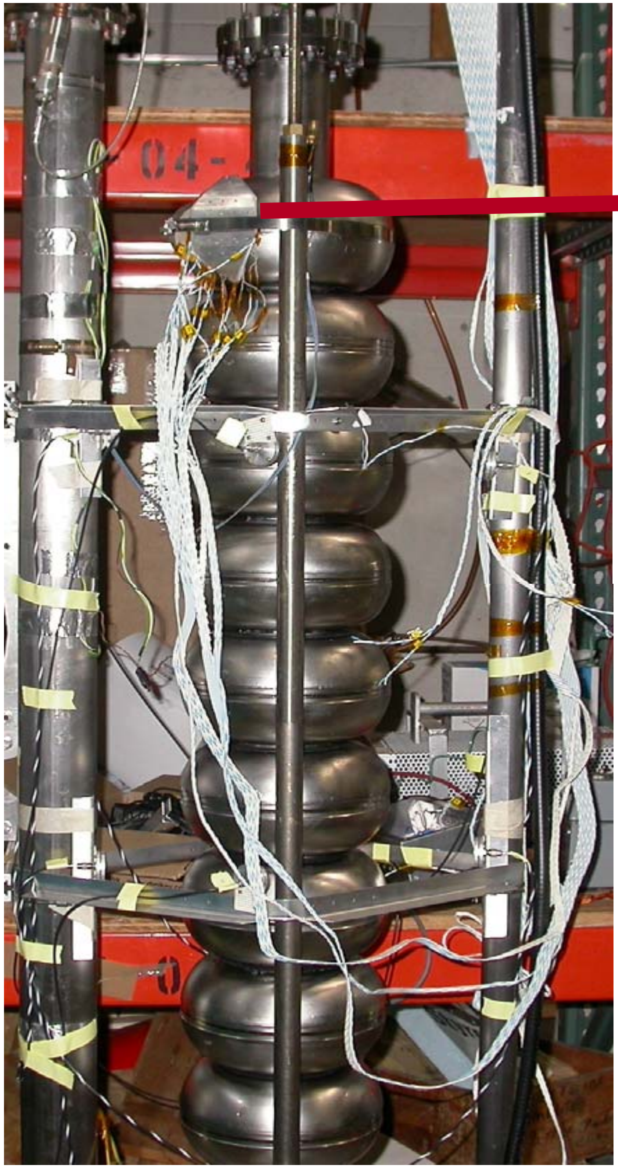
First Successful Use of OSTs to Locate Quench

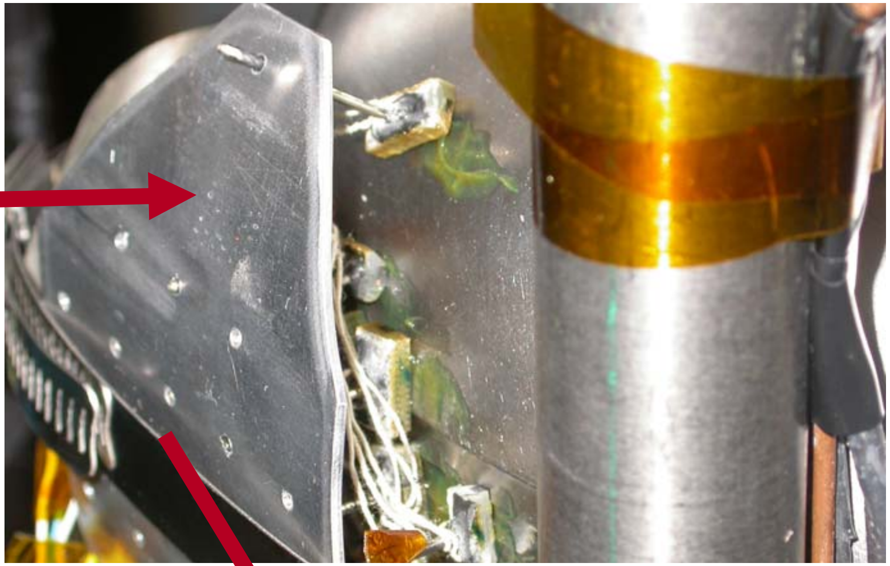


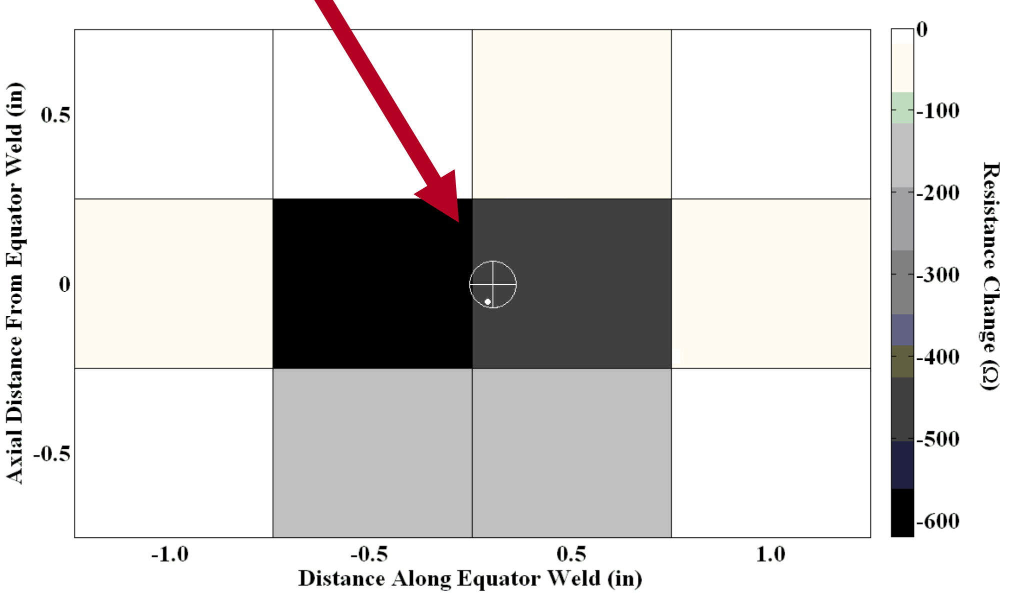


@ 2K (v_s = 16.68 m/s), horizontal scale = 5 ms/Div

Making Sure This Works!

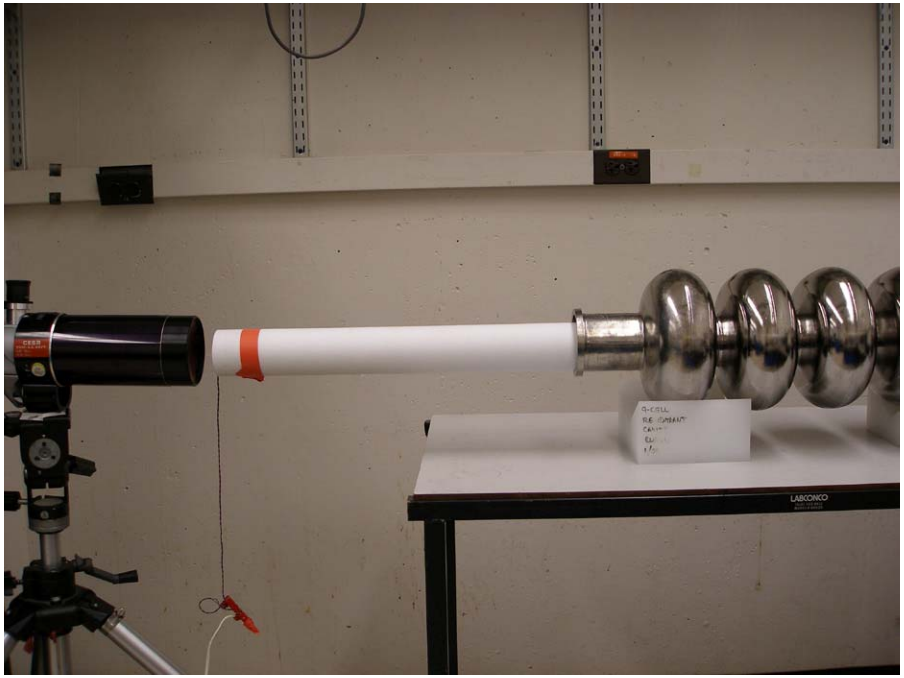






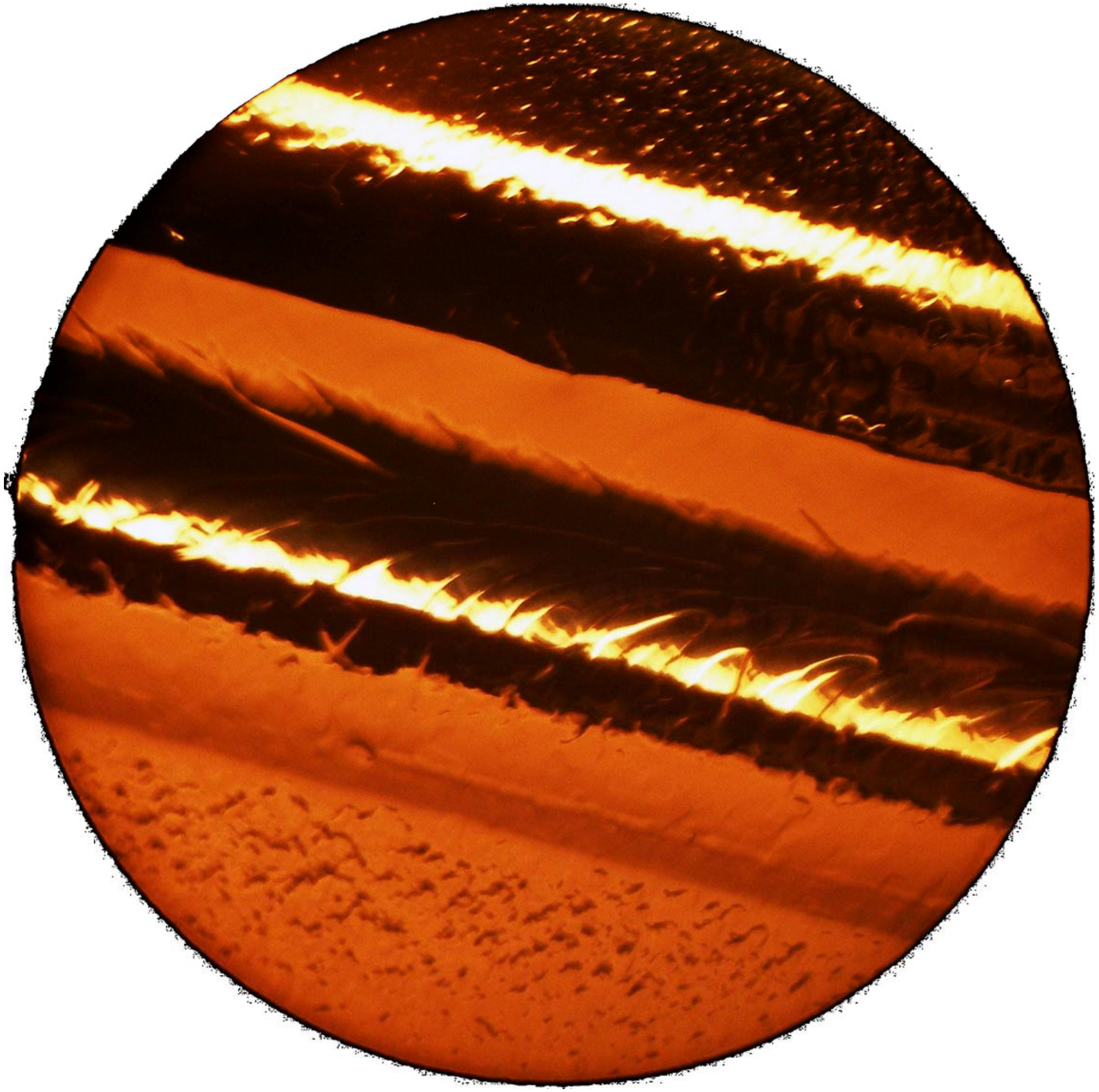
Defect Identification

- Use a Questar telescope and mirror/light source arrangement originally developed by Curtis Crawford while he was at Cornell



Defect Identification

- The defect near the weld in cell 1
- For scale, the weld is ~ 4 mm wide



Defect Identification

- By changing the drive frequency, it is possible to excite different modes that have higher fields in various cells
- For the π/9 mode the center cells went to ~ 40 MV/m accelerating while in π mode cell 1 quenched at 14.6 MV/m accelerating gradient
- By using different modes one can then identify other quench (defect) locations using the OSTs

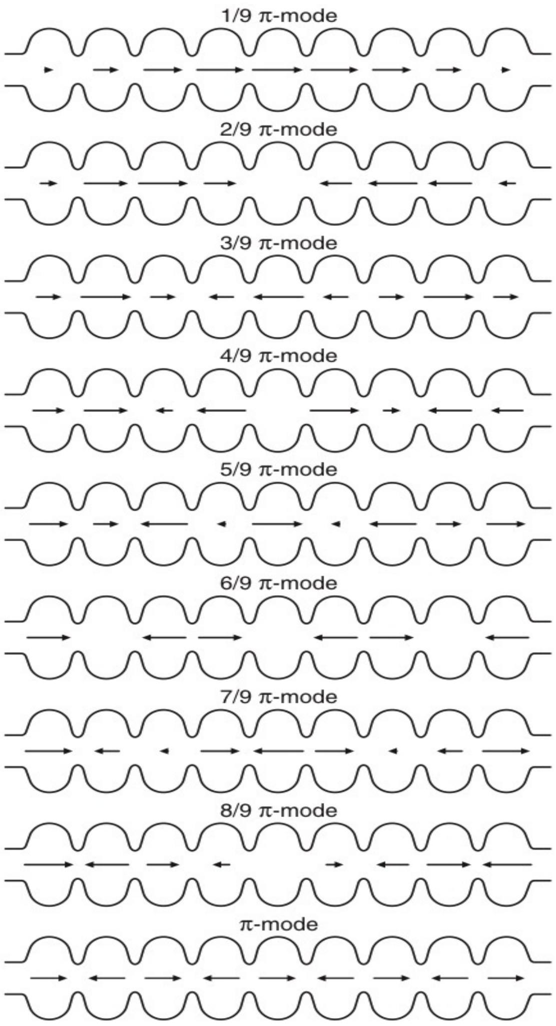


FIG. 2. The rf field amplitudes of the normal and fundamental modes (FMs) in 9-cell cavities.

Multi-cell Summary

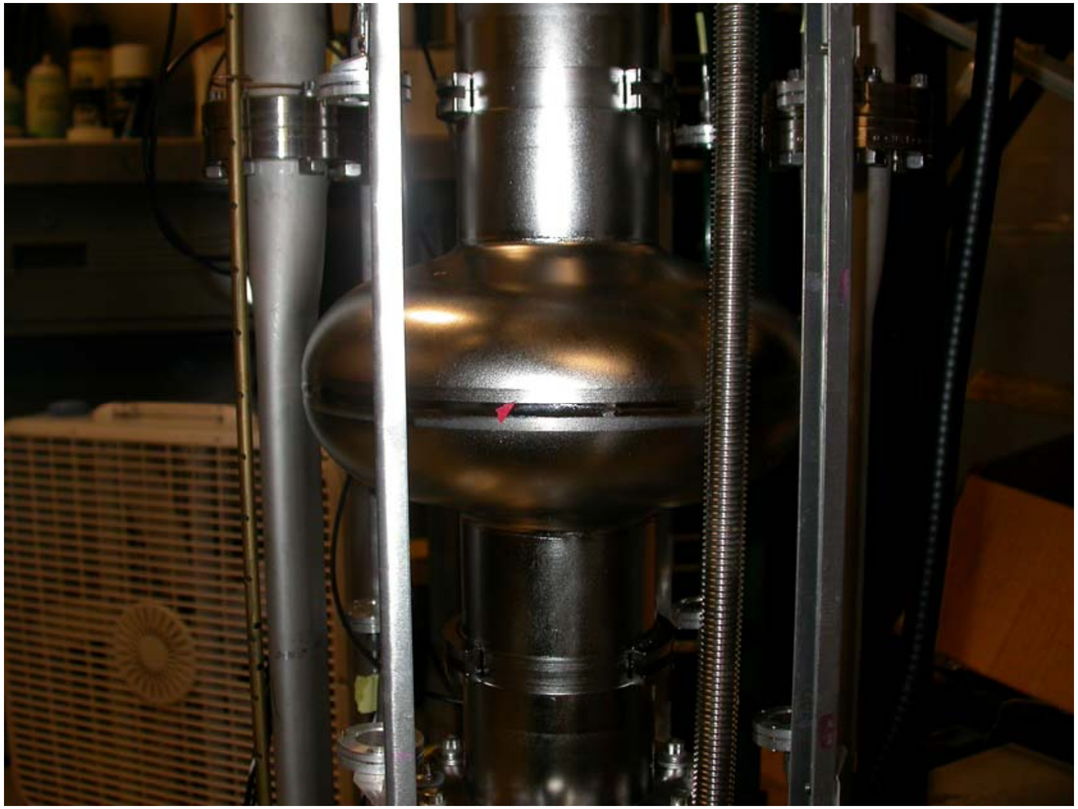
- Resistor thermometers verified quench location identified by the OSTs
- Visual inspection using our simplified telescope and lighting system identified a pit near the weld zone in cell #1 at the location indicated by both the OSTs and the thermometers
- Cavity has been tumbled for several weeks removing ~ 80 microns of material and the pit is no longer visible
- Cavity will receive ~ 200 micron electro-polish and then come to Jefferson Lab for hydrogen removal
- Cavity will then get a light electro-polish (~ 25 micron), high pressure rinse and low temperature bake
- And, the Type N connector has been replaced with the next test sometime in early 2009
- Stay tuned……

Single Cell Tests

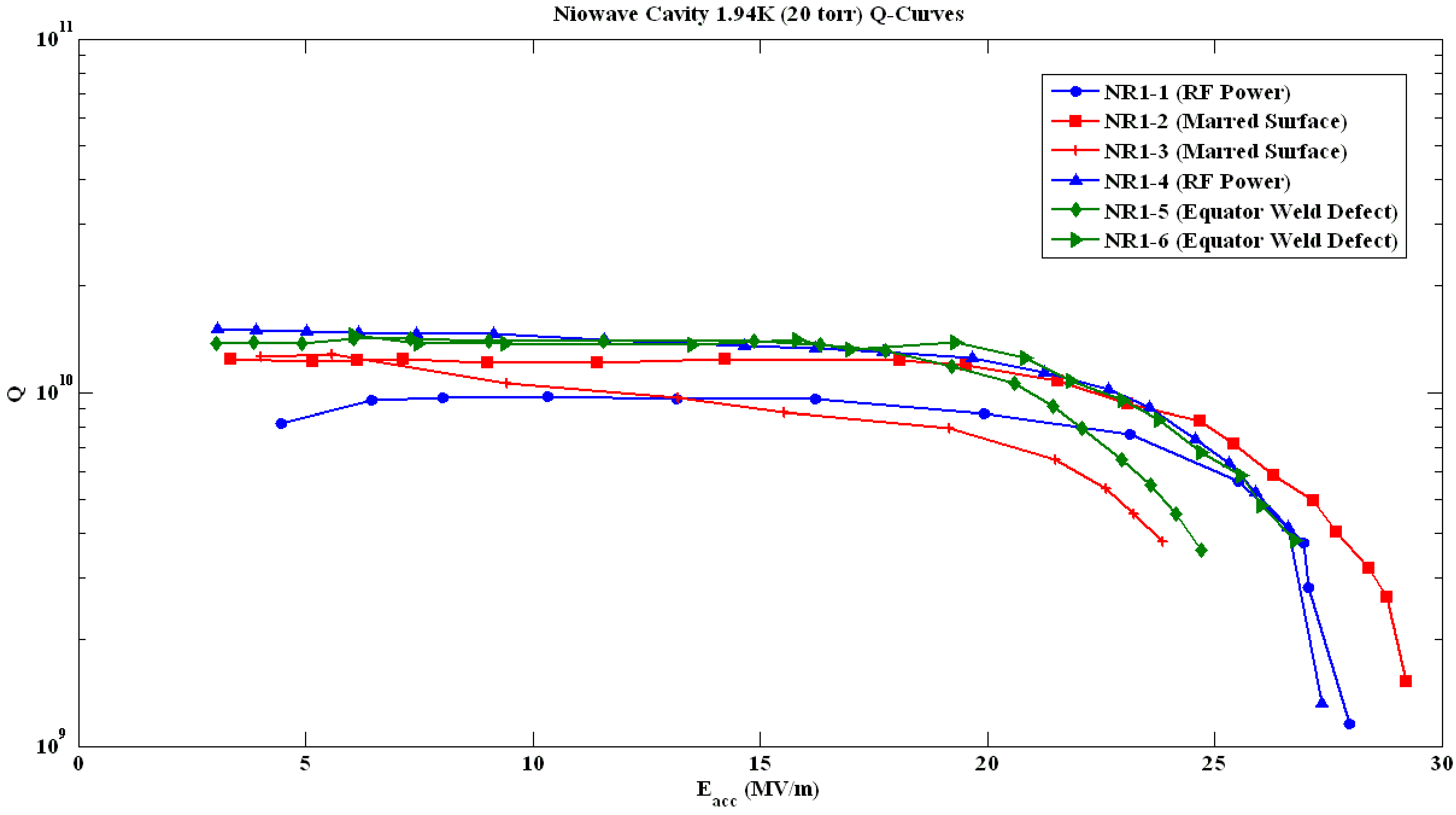
- Cornell has a program to test six Niowave single cell cavities for Fermilab
- Has been very useful in refining and confirming the usefulness of this new diagnostic technique using OSTs
- All six cavities have been tested and OSTs have been used in all the tests
- Today and tomorrow the single cell re-entrant cavity is being retested using the high pulsed power klystron setup (1300 MHz, 250 μsec pulse width, 1 MW peak power)
- Hope to see quench location move around depending on the klystron pulse parameters

Single Cell Tests

- Typical setup for single cell tests



Single Cell Tests

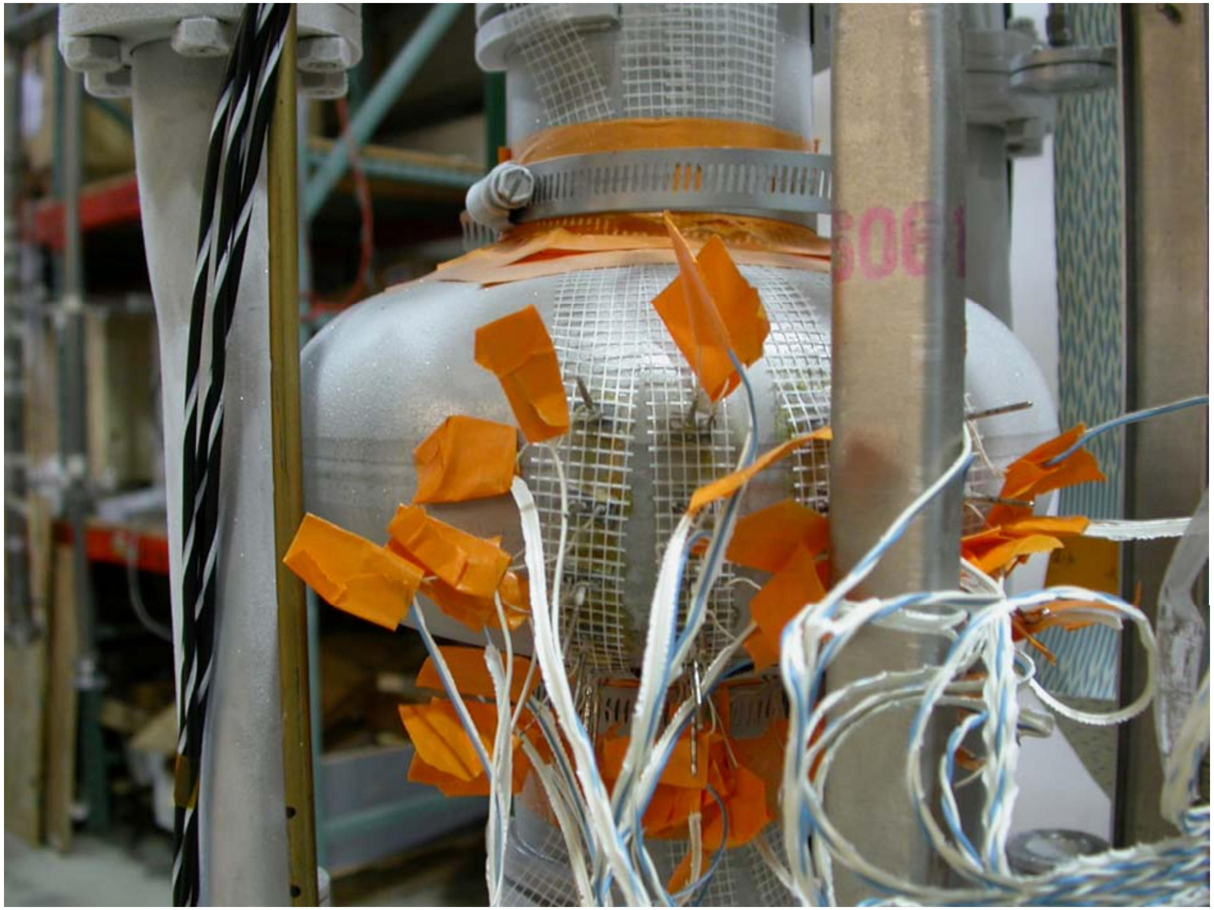


Single Cell Tests

Niowave Cavity	BCP (1:1:2) Etch	Q_0 (1.94 K)	Peak E_{acc}	Q at Peak E_{acc}	Field Limit
NR1-1	85 μm	8.2 e 9	27.9 MV/m	1.2 e 9	RF Power
NR1-2	113 μm	1.2 e 10	29.2 MV/m	1.5 e 9	Marred Surface
NR1-3	60 μm	1.3 e 10	23.8 MV/m	3.8 e 9	Marred Surface
NR1-4	254 μm	1.5 e 10	27.4 MV/m	1.3 e 9	RF Power
NR1-5	184 μm	1.4 e 10	24.7 MV/m	3.6 e 9	Equator Weld Defect
NR1-6	205 μm	1.5 e 10	26.8 MV/m	3.8 e 9	Equator Weld Defect

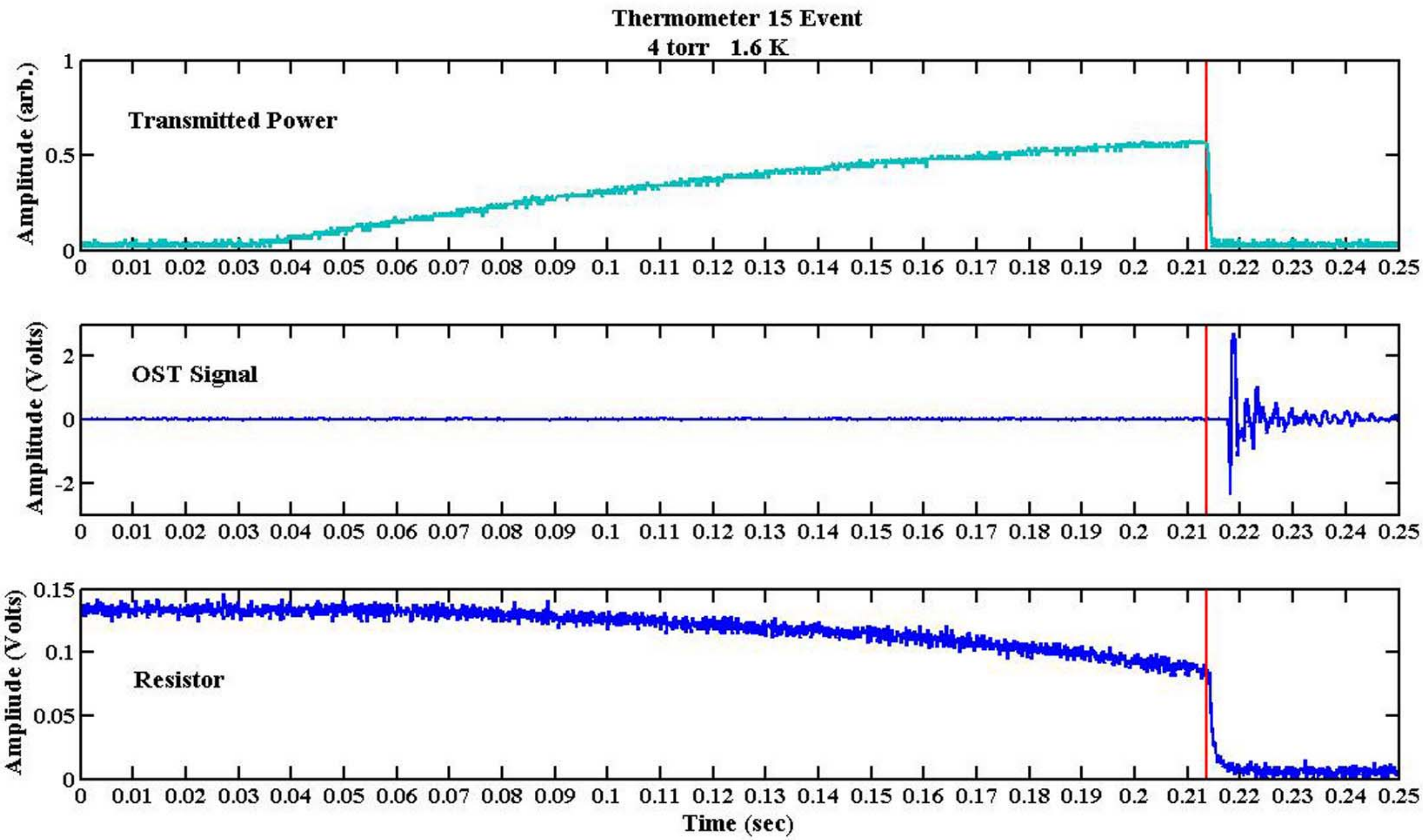
Single Cell Tests

- Niowave 3 with OSTs and thermometer array



Single Cell Tests

- Niowave #3 thermometer response



Single Cell Tests

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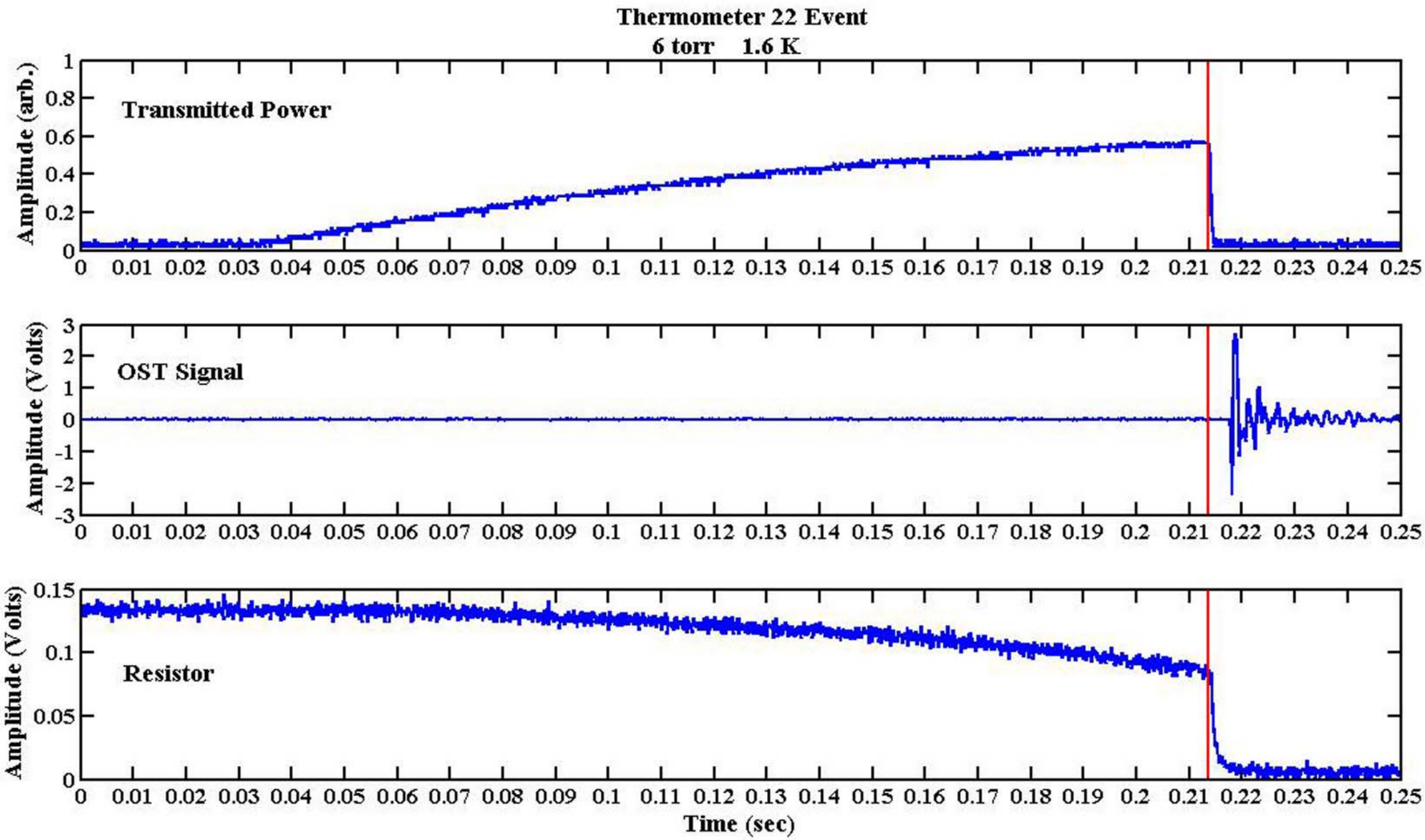
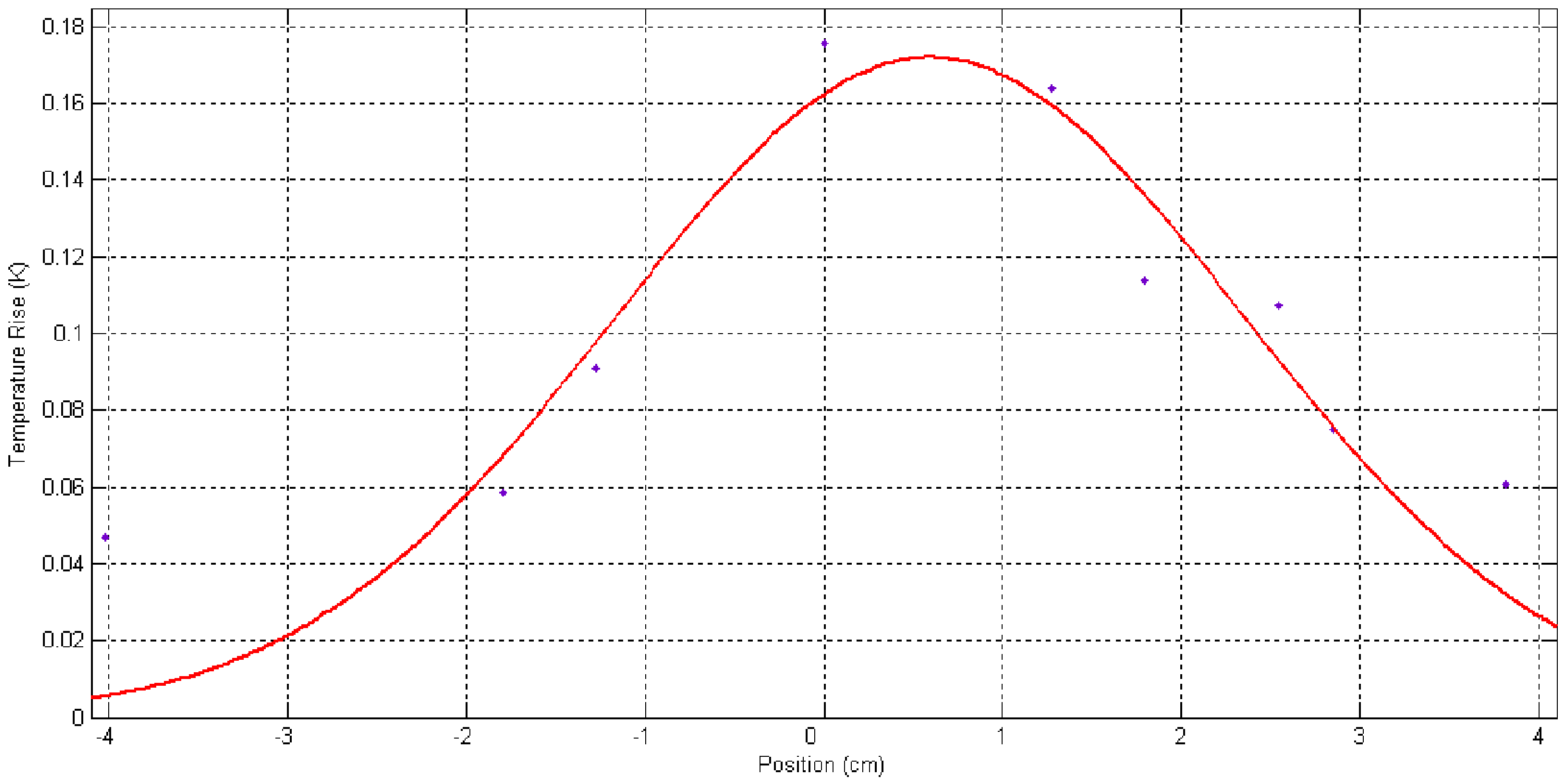


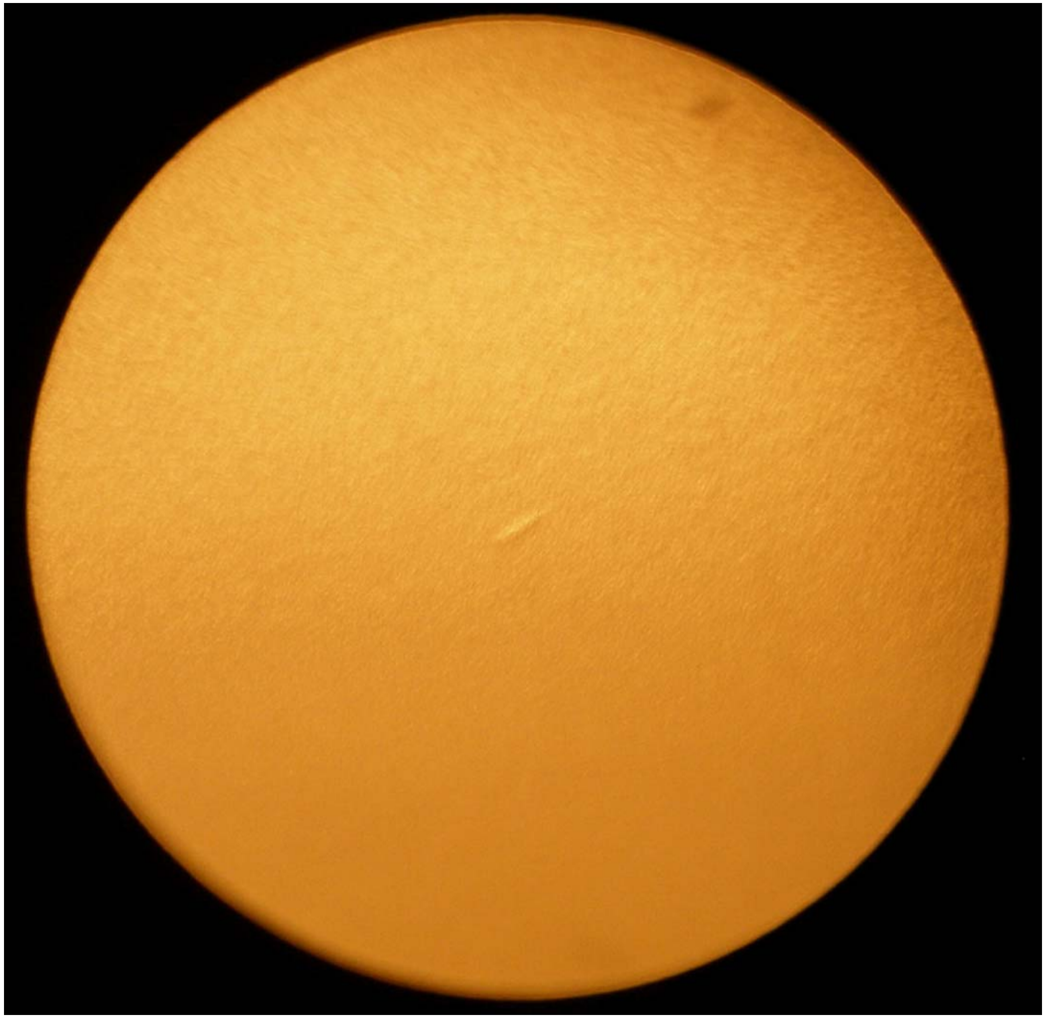
Single Cell Tests

- Niowave #3 temperature map



Single Cell Tests

- Defect in Niowave 3 in center of area indicated by the OSTs and the thermometers

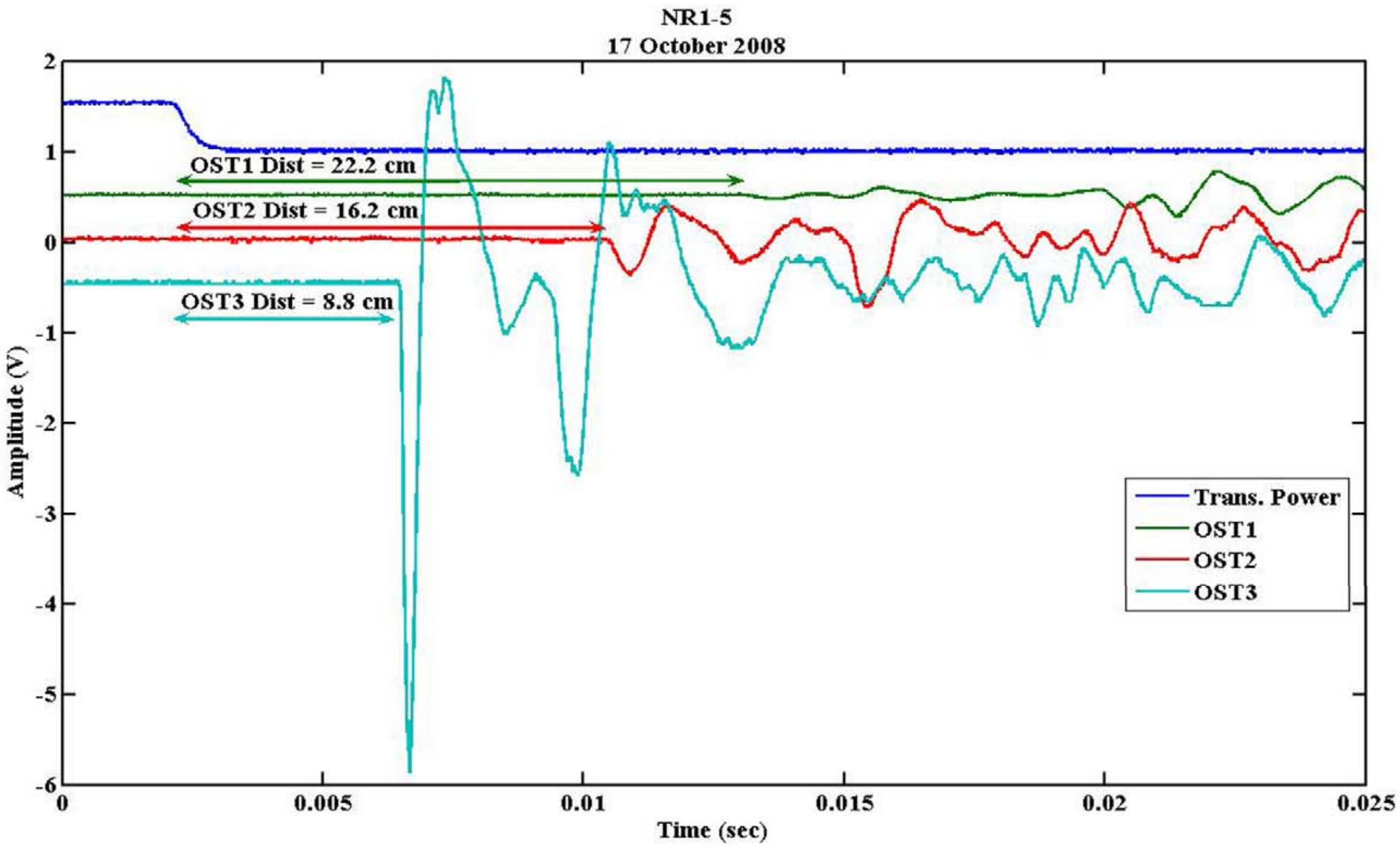


Single Cell Tests

- Die used to form the cavity cups before welding at Niowave

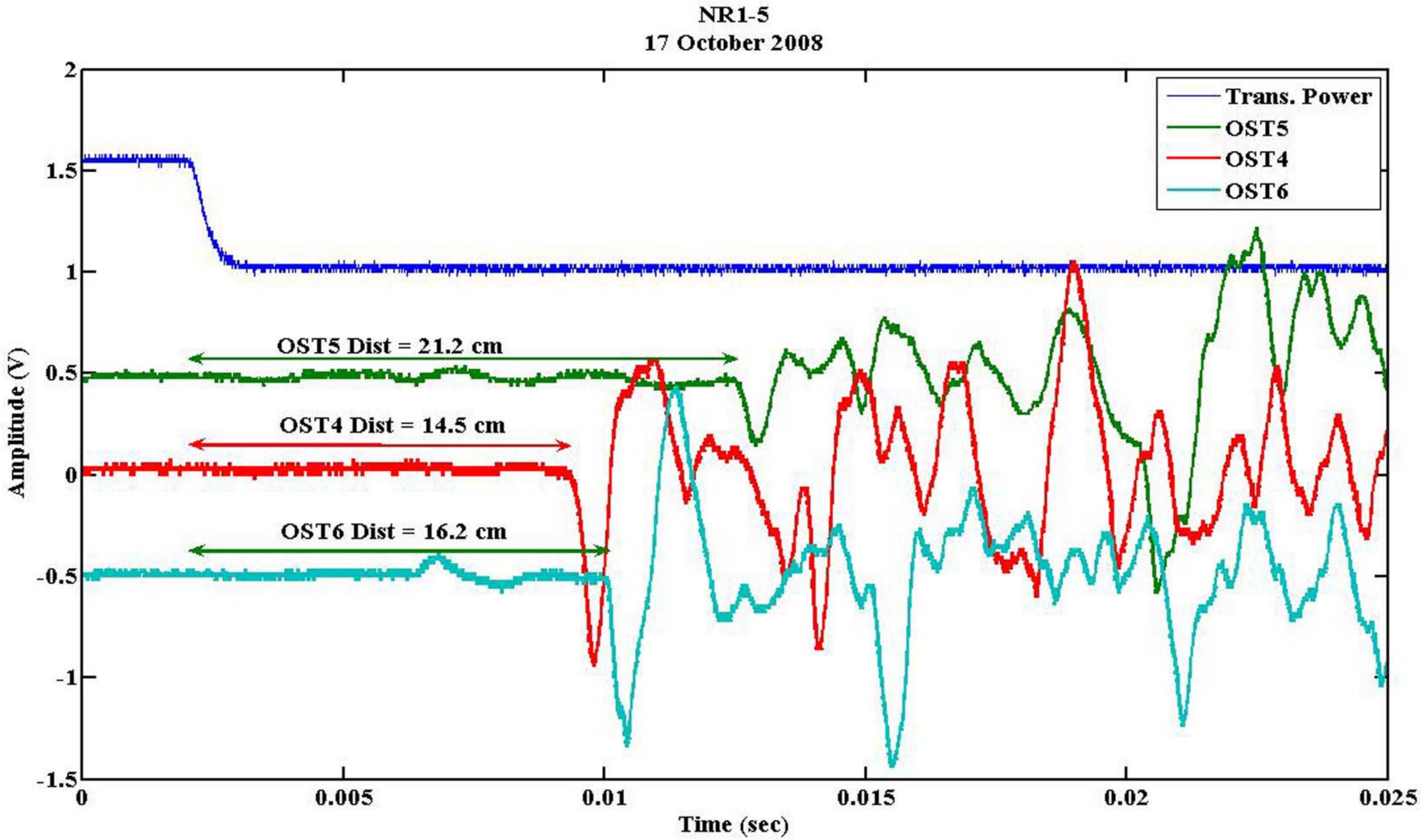
Single Cell Tests

- Niowave #5 waveforms



Single Cell Tests

- Niowave #5 waveforms



Single Cell Tests

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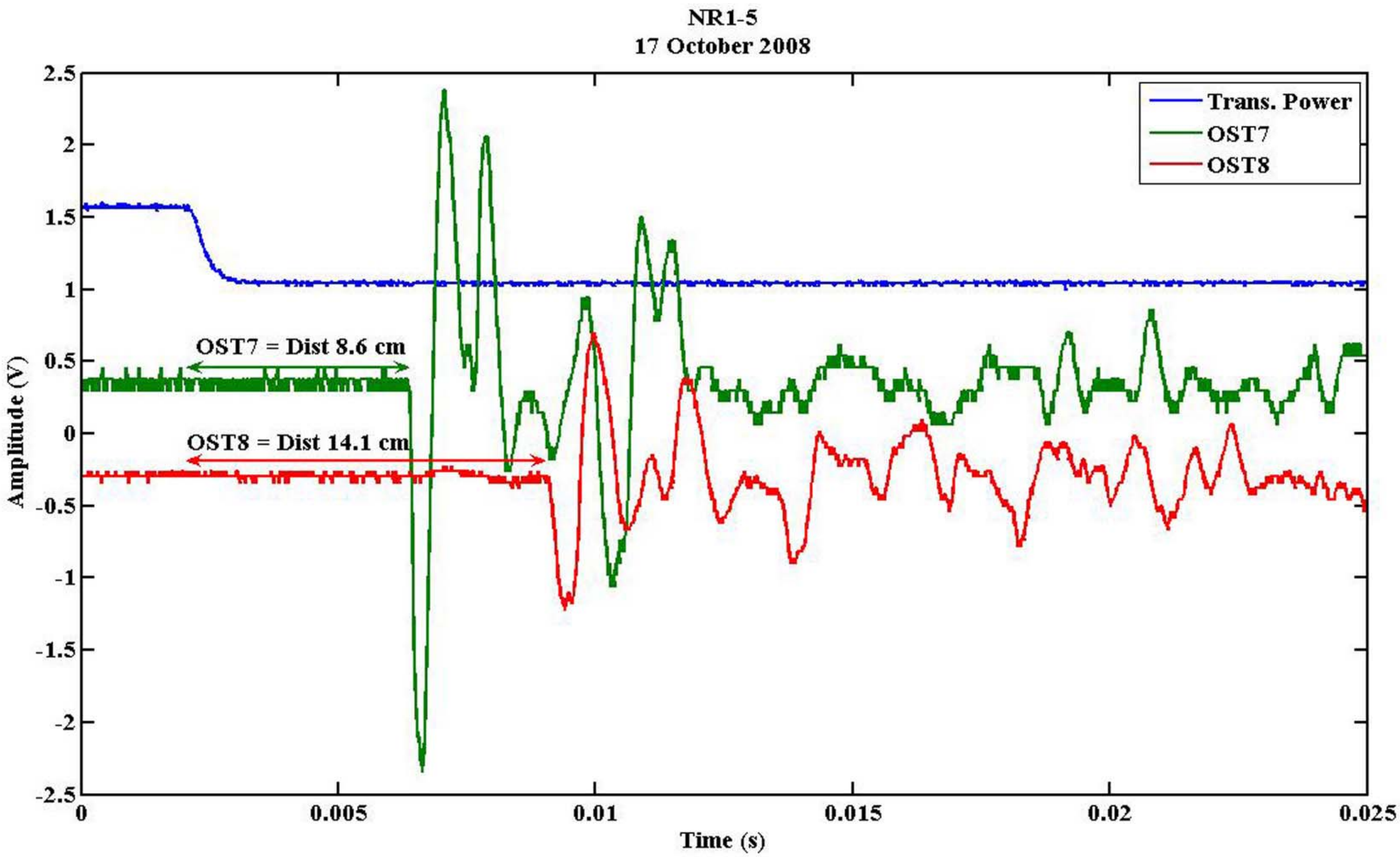
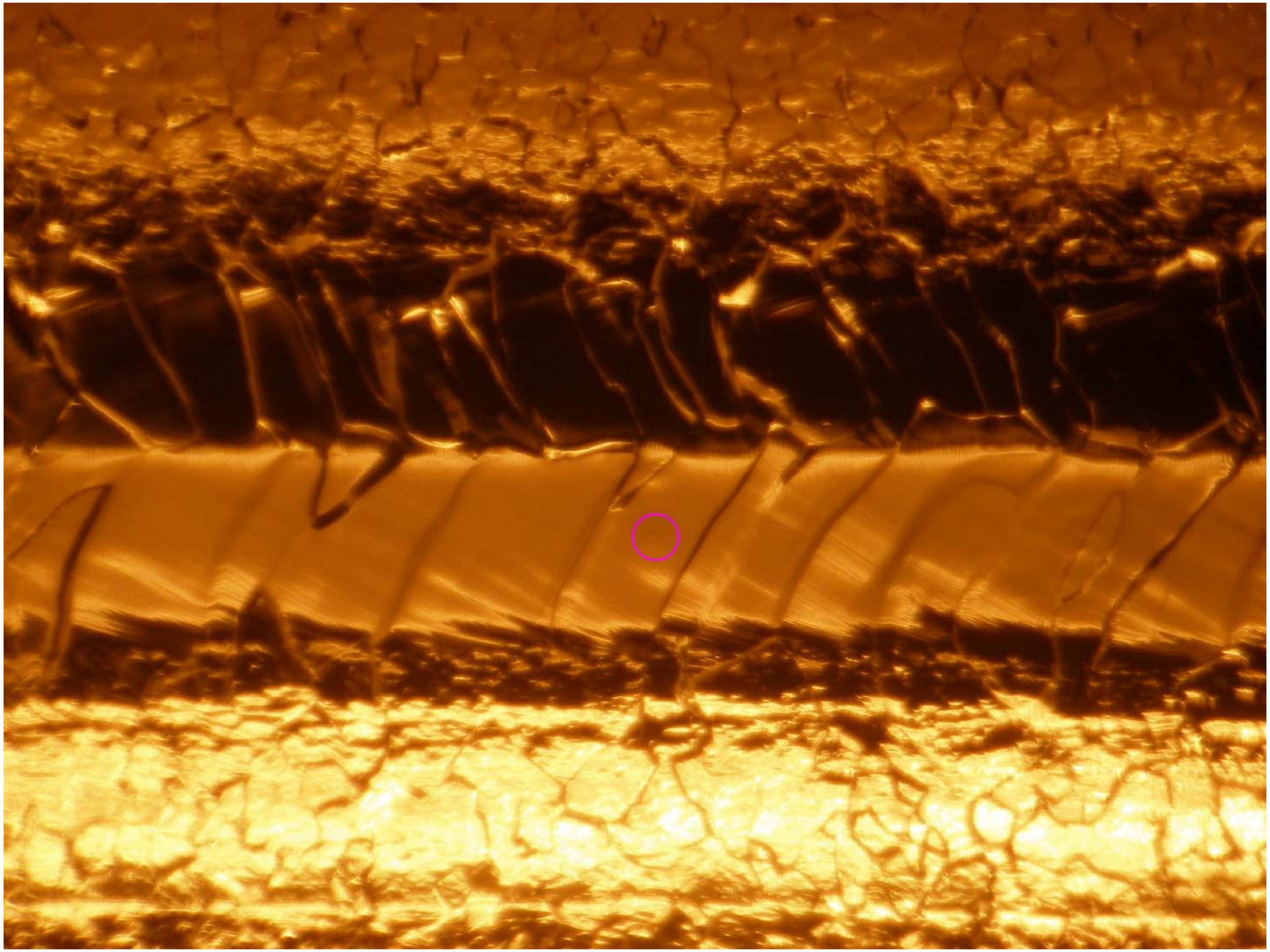


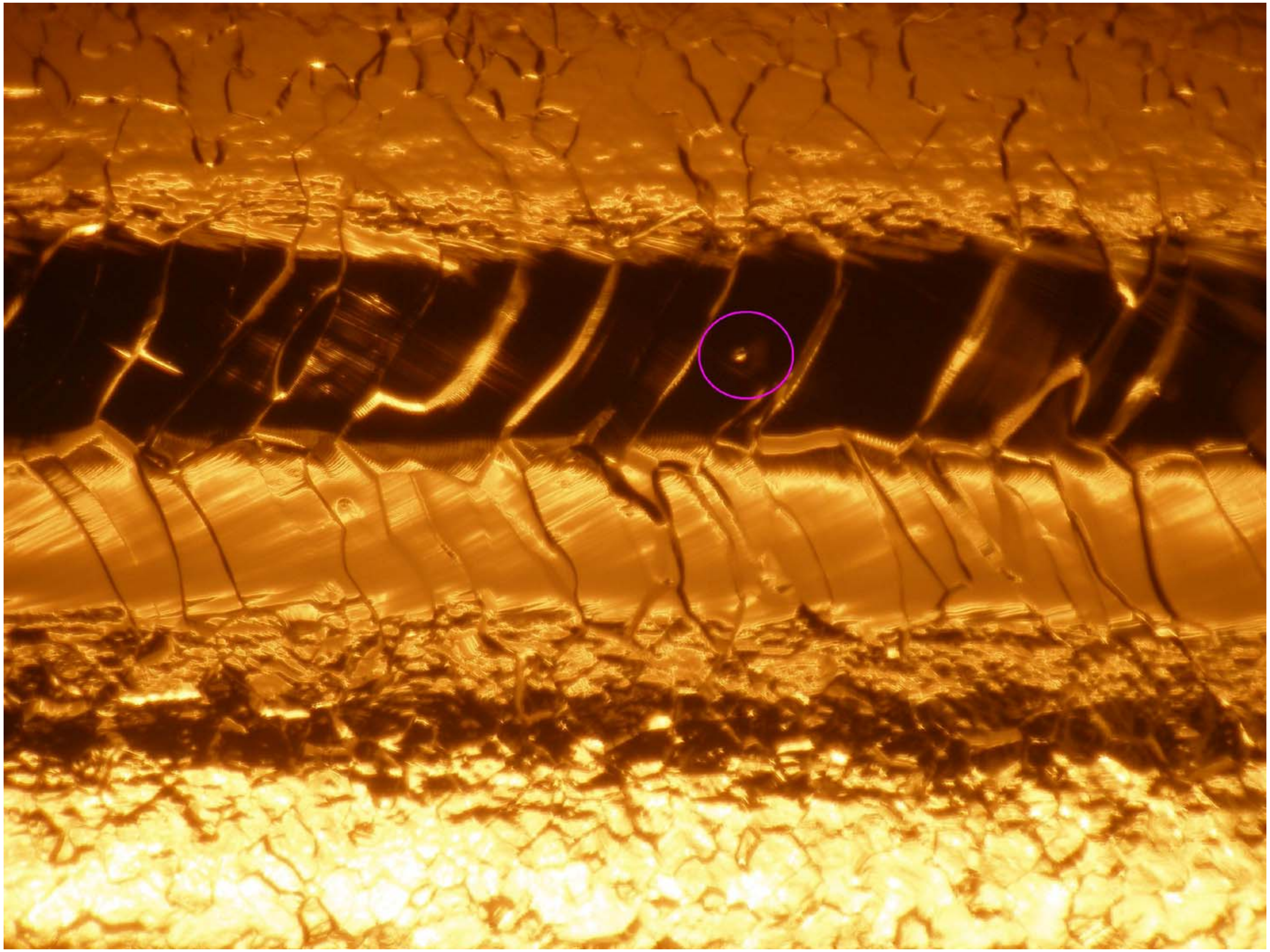
Single Cell Tests

- Defect in Niowave 5 orientation 1



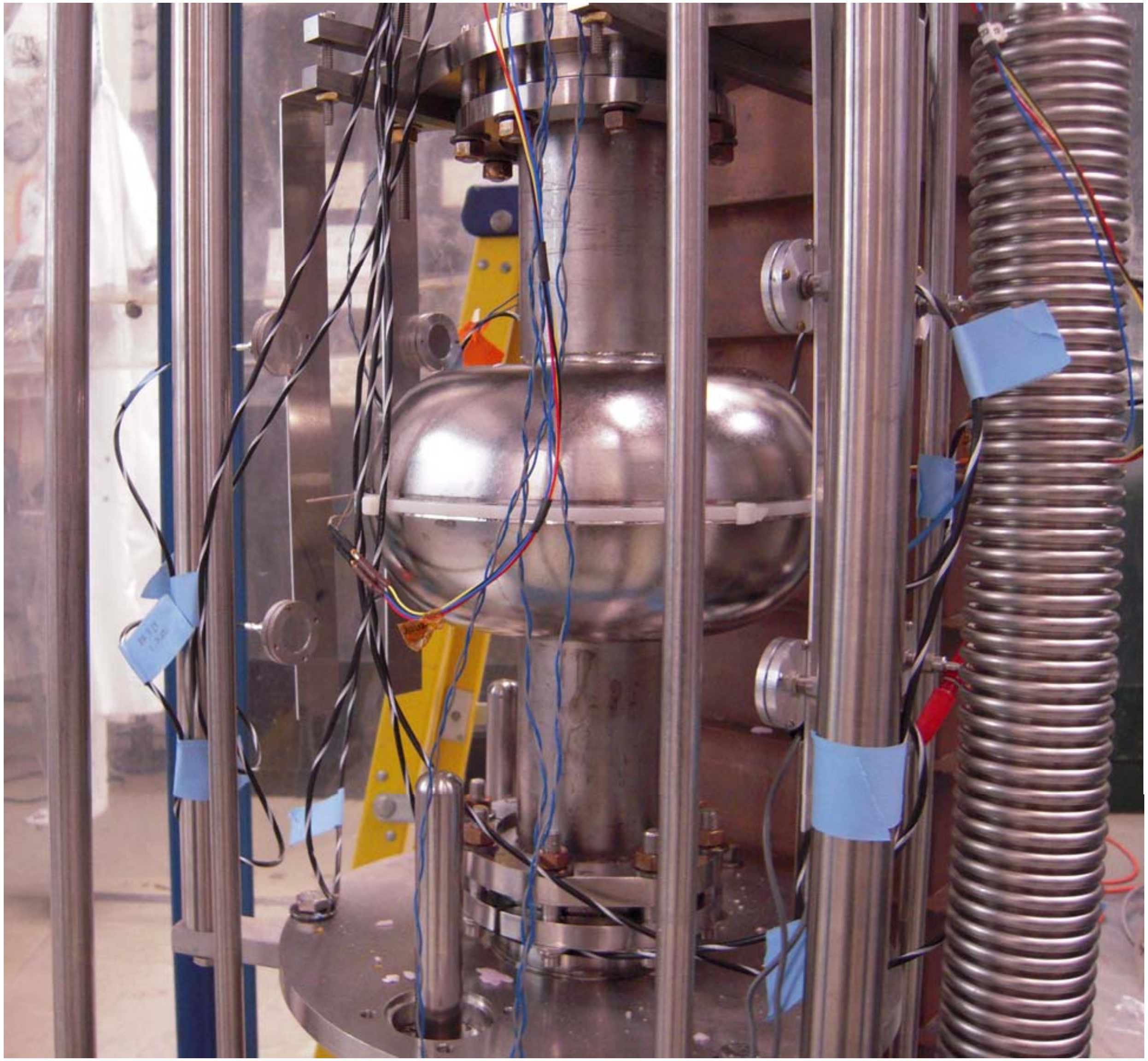
Single Cell Tests

- Defect in Niowave 5 orientation 2



Single Cell Tests

- Re-entrant Cavity with OSTs on klystron test stand



Single Cell Tests

- First test after light electro-polish with amplifier drive found quench site near equator weld but at an accelerating gradient of ~ 40 MV/m not 59 which it went to previously
- Had field emission at lower gradient but processed away
- Single cell re-entrant tests to try to see quench site move with different pulse power from klystron
- With short pulse can be sure of start time of the quench and verify that the OSTs are responding only to a point quench site

Future Plans and Conclusions

- OSTs are now in regular service during cavity tests at Cornell
- OSTs provide as simple and reliable method of determining the location of quench sites
- By powering multi-cell cavities to excite different cavity modes, quench sites in each cell can be identified
- Eight sensors versus thousands of resistors is a much simpler path
- Could provide a robust method of quench protection in multi-cell cavities in operating accelerators
- Very interested in establishing collaborations to use this technique elsewhere