Americas S0 Cavity (Tesla-style) Test Philosophy and Test Status

results from JLab, Cornell and FNAL

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GDE SCRF Meeting

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The Ideal Cavity Process/Test

- **Standard Processing Recipe**
  - Incoming cavity quality control checks.
  - Optical inspection of as-received cavity.
  - Bulk electro-polishing of ~150 um.
  - Ultrasonic degreasing.
  - High-pressure rinsing.
  - Hydrogen degassing at 600 deg C.
  - Field-flatness tuning.
  - 20 um electro-polishing.
  - Ultrasonic degreasing.
  - Field-flatness verification and retuning if <95%.
  - High-pressure rinsing.
  - Assembly and vacuum leak testing.
  - 120 deg C bake.
  - Vertical dewar test.
- **Standard Testing Recipe**
  - Hold at ~100 K during cool down to check for Q disease.
  - Q vs. T measurement during cool down.
  - Q vs. E measurement on π mode. RF process as needed.
  - Q vs. E measurement on all other modes. RF process as needed.
  - Final Q vs. E measurement on π mode.
  - Notes:
  - All Q vs. E measurements to include radiation data logging.
  - Utilize nine-cell temperature-mapping system if available.
- **Diagnostic Techniques**
  - Determine limiting cells based on mode measurements.
  - If nine-cell temperature-mapping was not employed, apply thermometry to limiting cells and retest.
  - Perform optical inspection of limiting cells.

S0-Americas (9-cell Tesla-style) Cavity Tests

- 9 cavities
  - 5 from Accel (qualified vendor)
  - 4 from AES (new vendor)
- At least 45 vertical tests at three labs
- Test philosophy: get highest gradient
  - Process reproducibility
  - New process development
  - New test stand commissioning
  - Diagnostic instrumentation development

S0-Americas (9-cell Tesla-style) Cavity List

P. Pfund, update December 3, 2007

The Cavity Report

Cavity_Listing_2007-12-03.xls

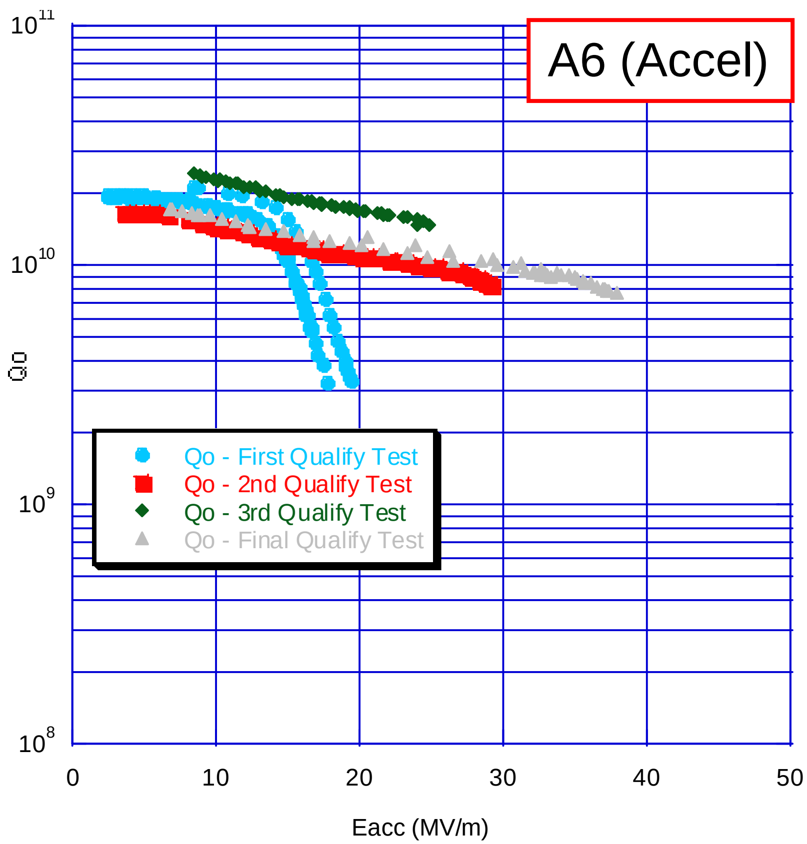
Lab	Cavity Name	Current Location	Current Use	Designated Use	Reported Gradient	Gradient Limitation	Comments
FNAL	AES001	enroutet to KEK			16.0 MV/m (Jlab)	Quench	(as of 3Dec07) AES1 has completed detailed thermometry testing at Fermilab and is en route to Japan for optical inspection and subsequent processing and testing.
FNAL	AES002	at Jlab	Under test		19.6 MV/m (Jlab) 26 MV/m (Jlab) 32.6 MV/m (Jlab)	Quench Quench Quench	(from Rongli Geng, 26Nov07) It is a pleasure for me to announce the final result of the latest AES2 test, following the 4th light EP. The highest accelerating gradient is 32.6 MV/m and quench is the limit. There was some cable heating at higher gradient
FNAL	AES003	at Jlab	Under test		17.6 MV/m (Jlab) 20 MV/m (Jlab)	Quench Quench	(as of 3Dec07) AES3 nine-cell will ship from JLab to Fermilab prior to Christmas. Activities to be completed at JLab prior to shipping include a bead-pull measurement to verify field flatness, high-pressure rinse, assembly, and evacuation. The cavity wil
FNAL	AES004	at Jlab	Under test		28 MV/m (Jlab) 19.5 MV/m (Jlab) 17 MV/m (Jlab)	Field Emission Cable	To be tested again after HPR.
	AC 5	At Cornell	On loan from ACCEL				Has dent in HOM can at power coupler end of cavity.
FNAL	AC 6	At Jlab	Tested	Dressed, high gradient testing (S1).	37.8 MV/m (Jlab)	Field Emission	(as of 3Dec07) Accel 6-8 nine-cell cavities will be shipped from JLab to Fermilab.
FNAL	AC 7	At Jlab	Tested	Dressed, high gradient testing (S1).	31.9 MV/m (Jlab)	Quench	(as of 3Dec07) Accel 6-8 nine-cell cavities will be shipped from JLab to Fermilab. Accel7 will then be delivered to ANL for commissioning of the electro-polishing stand. In case of split shipments, Accel7 will be sent first so Mike can get started.
FNAL	AC 8	At Jlab	Under test	NML-CM2	25 MV/m (Cornell)	Field Emission Quench	(as of 3Dec07) Accel 6-8 nine-cell cavities will be shipped from JLab to Fermilab.
FNAL	AC 9	At Cornell	Under test	NML-CM2			Will be sent to Jlab after testing at Cornell.

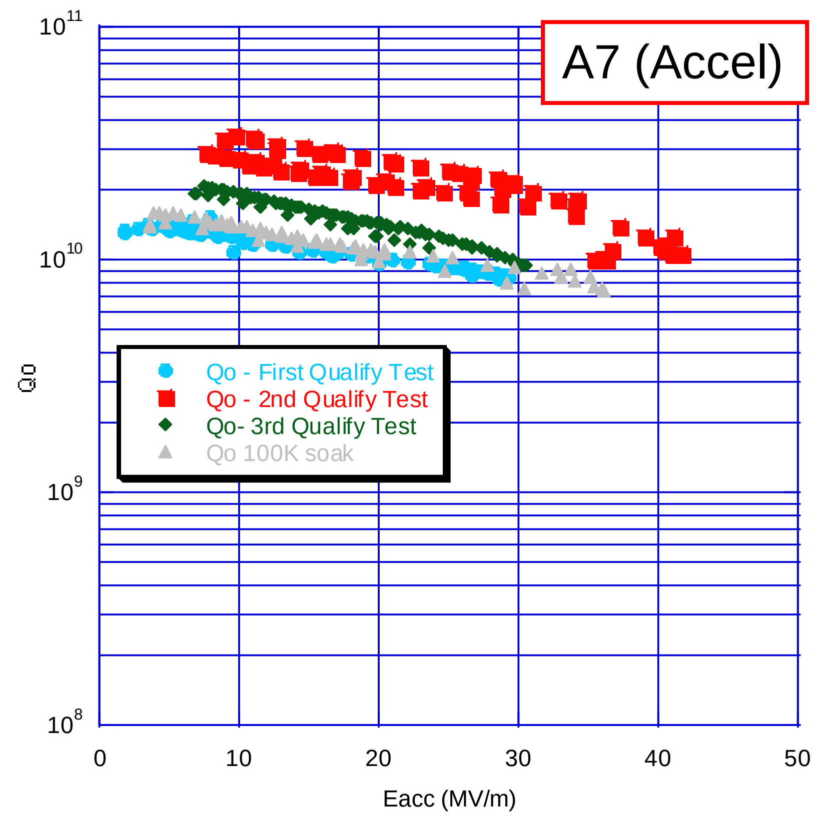
http://tdserver1.fnal.gov/project/ILC/S0/S0_coord.html
Selection showing cavities designated for S0-Americas

JLab: Process reproducibility

J. Mammosser, TTC Meeting at Fermilab, April 2007

- Accel cavities – qualified vendor, same treatment for all cavities
- All curves but one limited by quench; A6 final test limited by FE
- Large distribution of quench gradients with multiple tests of same cavity
- Best(last) gradient 38(38) MV/m for A6, and 42(32) MV/m (A7)





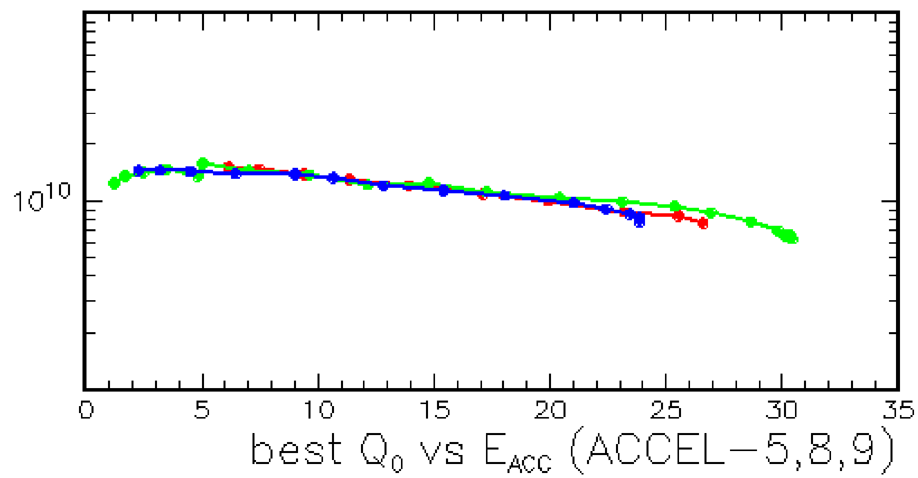
Cornell: Process development

Ashmanskas & Padamsee SRF 2007

ACCEL 5	Processing	Max E_{acc}	Limitation
2006-09-06	144μm EP ($\frac{0.5\text{Hz}}{30°\text{C}}$)	16 MV/m	Q drop
2006-11-14	degas	17 MV/m	Q drop, FE
2006-12-19	3μm BCP	15 MV/m	Q drop
2007-03-02	25μm EP ($\frac{0.5\text{Hz}}{36°\text{C}}$)	24 MV/m	quench
2007-06-15	70μm EP, degas, 30μm EP (2Hz, 35°C)	18 MV/m	quench, FE

ACCEL 8	Processing	Max E_{acc}	Limitation
2006-04-21	60μm BCP	17 MV/m	quench
2006-05-24	60μm BCP	26 MV/m	Q drop
2007-02-15	25μm EP ($\frac{0.5\text{Hz}}{32°\text{C}}$)	30 MV/m	quench
2007-05-09	100μm EP, degas, 30μm EP (2Hz, 35° C)	26 MV/m	Q drop
2007-07-20	7μm EP (2Hz, 35° C)	24 MV/m	Q drop

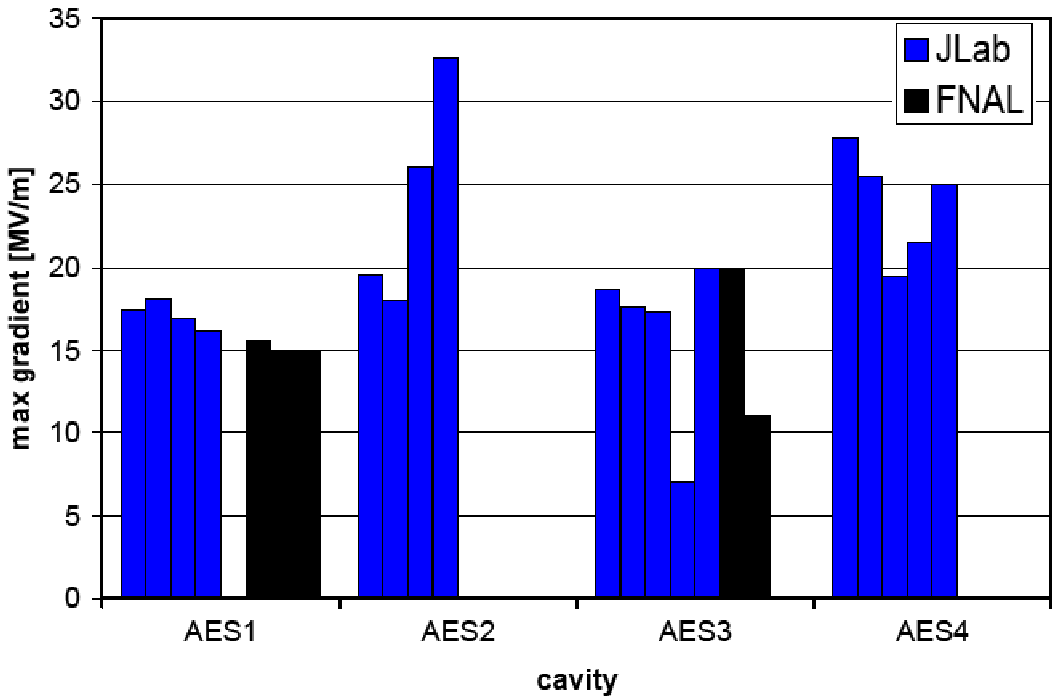
ACCEL 9	Processing	Max E_{acc}	Limitation
2007-08-15	160μm EP, degas, 40+30μm EP ($\frac{1\text{Hz}}{31°\text{C}}$)	26 MV/m	quench, FE
2007-09-15	30μm EP (1Hz, 32°C)	26 MV/m	quench



- Development of Vertical EP (VEP) etc.
- HPR and assembly procedures capable of reaching high gradient
- SRF development & training with about one/month 9-cell cavity process/test

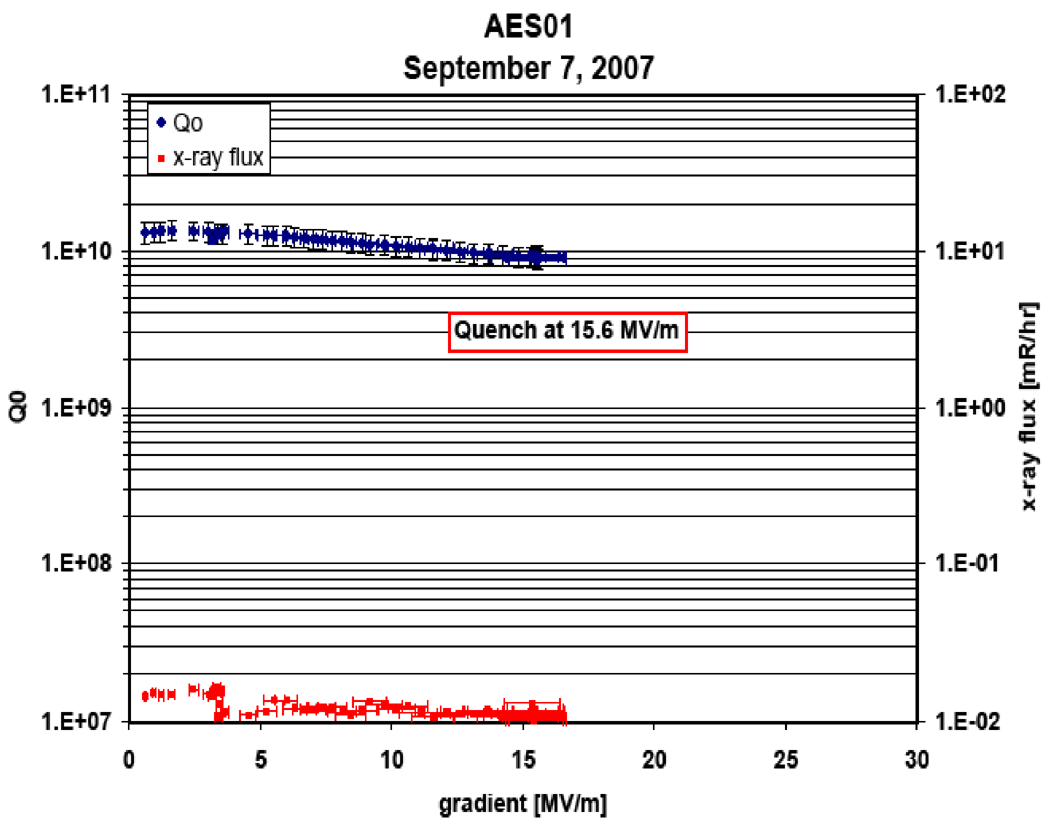
JLab/Fermilab: new vendor qualification

- Four cavities from new (9-cell Tesla-style) cavity vendor AES
- Standard JLab surface treatment
- Best cavity test gradient: AES2 at 33 MV/m
- Mode measurements and thermometry used to locate quench site of AES1 and AES3
- Optical inspection of AES1 using Kyoto/KEK system
- Optical inspection of AES4 irises using JLab Questar system



Fermilab: Test stand commissioning & diagnostic instrumentation commissioning

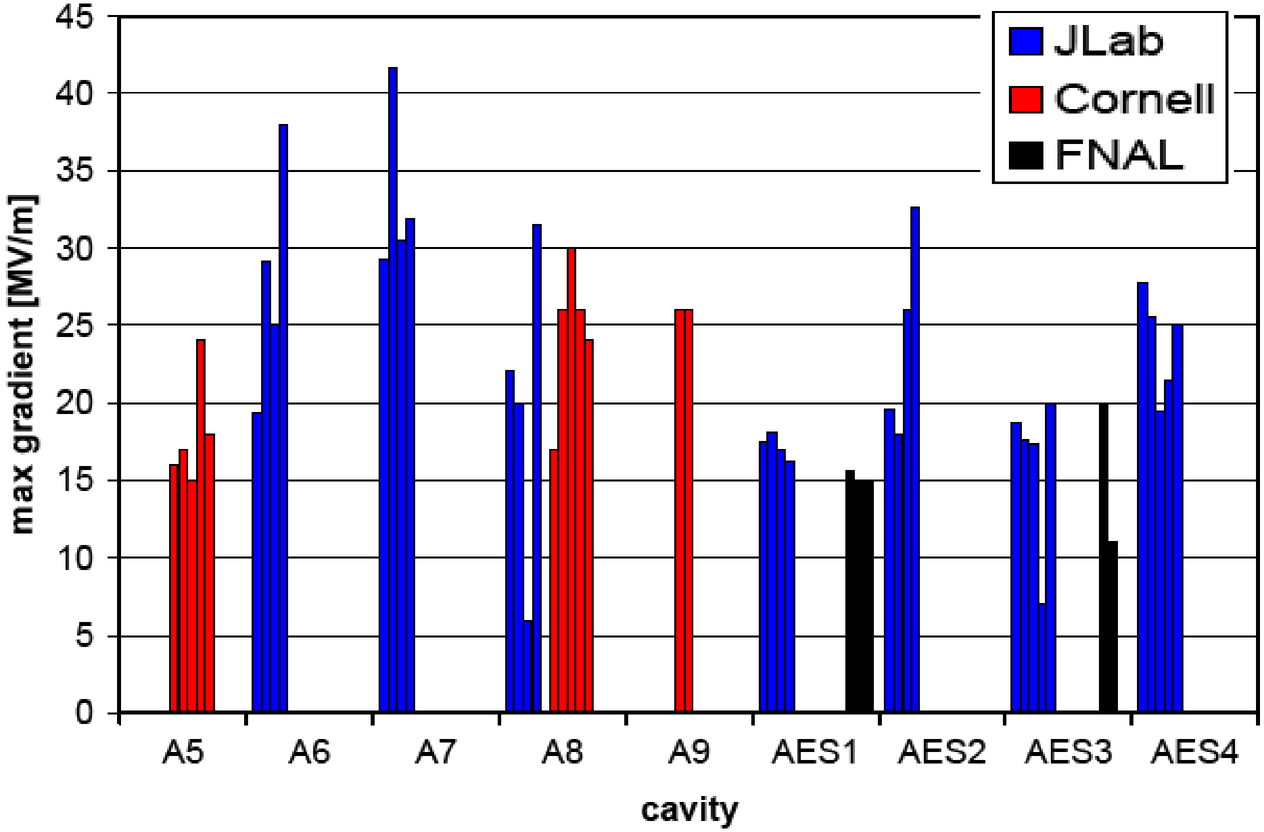
AES1: First Fermilab 9-cell test in new facility



- First Fermilab Vertical Cavity Test Facility 9-cell test September 2007
- AES1 and AES3 tests consistent with previous JLab measurements (only surface treatment in between was HPR at JLab)
- AES1 and AES3 tests included thermometry for quench site location; mode measurements only a few times
- Variable coupler commissioning

Summary of 9-cell (Tesla-style) Test Results

- >45 tests at JLab, Cornell and Fermilab
- Highest gradient in a test was 42 MV/m - A7, 2nd test of 4
- Four of the eight cavities made 31.5 MV/m at least once



Instrumentation/techniques employed for data shown in this talk

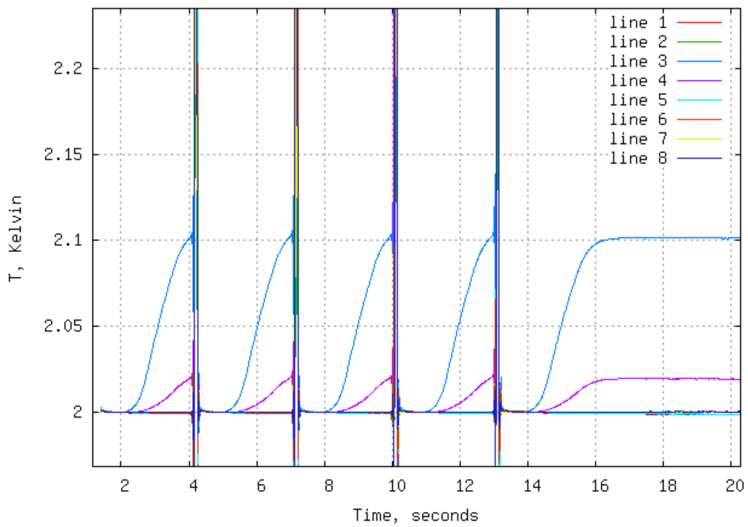
- Fast thermometry for quench site location
- Questar optical inspection of suspicious sites – so far on irises only
- (Kyoto/KEK optical inspection)
- Second sound sensors
- Mode measurements
- Variable coupler

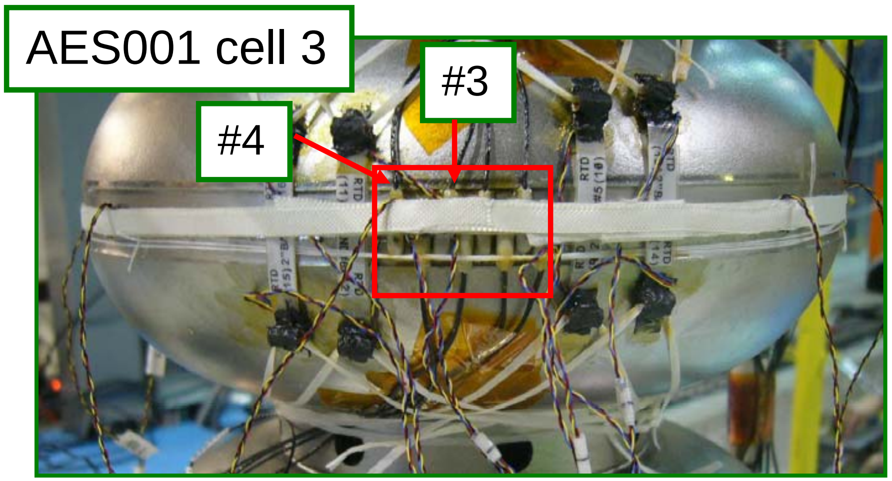
Fermilab: Fast Thermometry

FT reference: Orris et al., WEPMN105, PAC07
AES1 Results: Ginsburg et al., TUP47, SRF2007

- "fast" read-out electronics (10 kHz)
- Cernox RTD sensors (precise calibration, expensive)
- Flexible placement of sensors
  - Attachment to cavity surface with Apiezon grease and thin nylon cord or G10 band
- Used for AES1 and AES3 tests, to locate isolated quench spots, both at JLab and Fermilab

AES1: Temperature rise ~0.1 K over ~2 sec seen in sensors #3 and #4 before quench





JLab: Questar inspection of AES4

AES4 defect (~100 µm in dia.) near iris

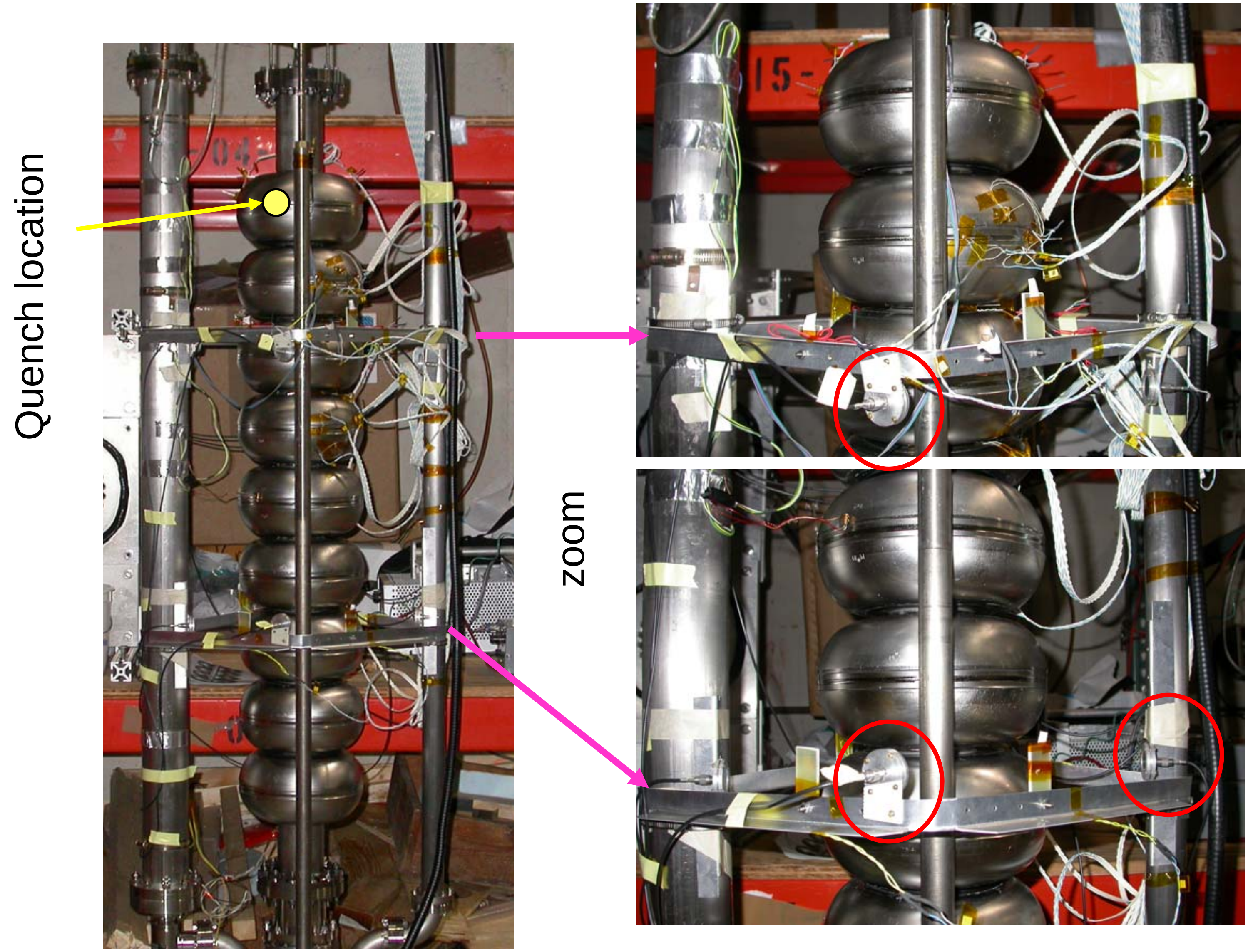
- Questar long-distance microscope for optical inspection
- To date, only used for line-of-sight inspections
- Could be enhanced for inspection of full cavity inner surface
- Located defect on iris of AES4, suspected from mode measurements of inducing field emission

Cornell: Quench Detection with 2nd Sound

- 9-cell *re-entrant* cavity (AES) quenches in the π-mode at 13 – 14 MV/m.
- 2nd sound has been used to find quench location to several mm accuracy
- Attempt to confirm with regular thermometers failed due to detached sensors
- Pass-band modes have been studied
  - Data under analysis
  - Quench is in end-cell only
  - Preliminary result: only end-cell shows quench
  - middle cell E_{acc} > 30 MV/m

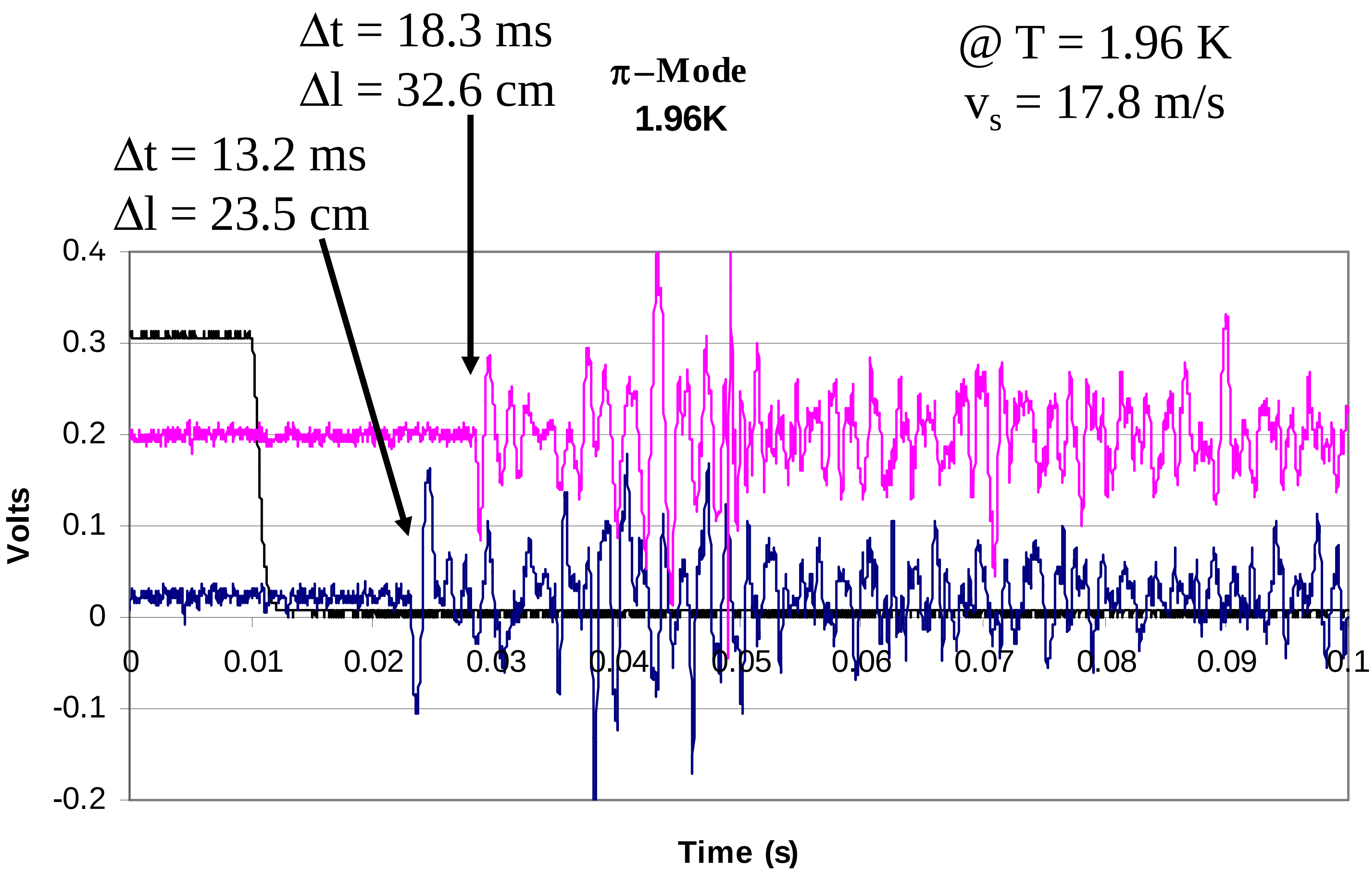
Cornell: Quench Detection with 2nd Sound

AES re-entrant cavity (LR9-1) with 8 2nd sound sensors



Cornell: Quench Detection with 2nd Sound

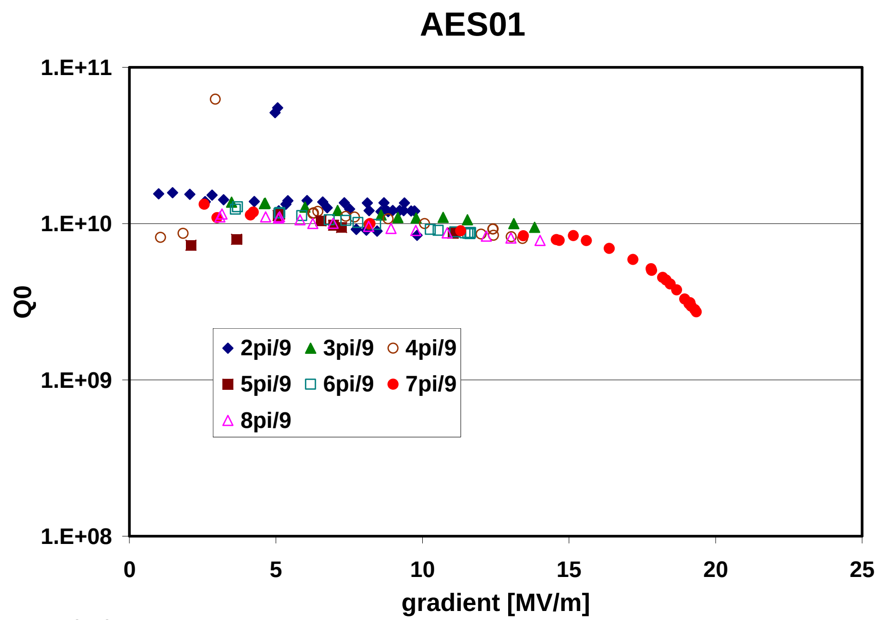
Sample Result for : 2nd Sound Quench Detection

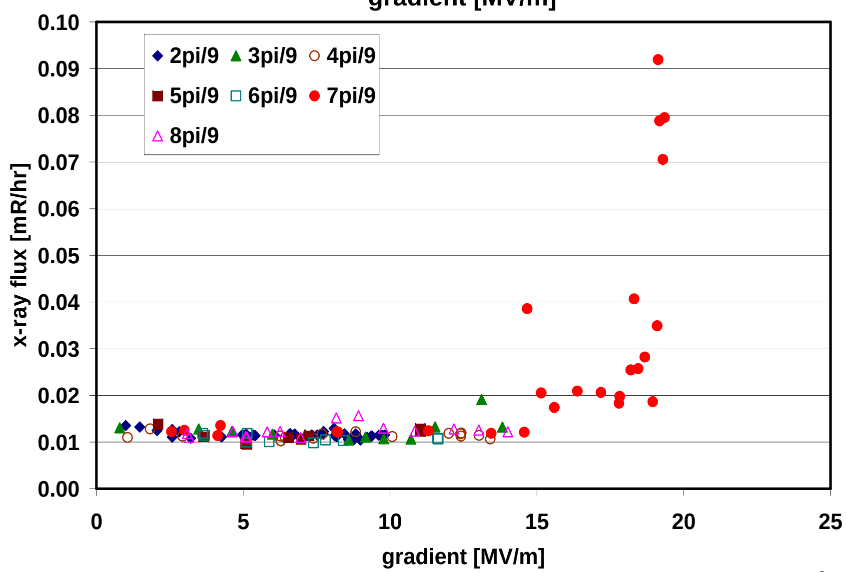


Mode Measurements

- Mode measurements – determine cavity performance limiting cell(s)
  - Determine limitation to within one (cell 5) or two cells
  - Measure Q vs. Eacc of TM010 passband modes
  - Determine total cavity stored energy at maximum input power just before quench for each passband mode
  - Maximum gradient or stored energy for each cell extrapolated from measurement using Superfish simulation by H. Wang (JLab), or DESY method of 9 coupled oscillators, etc.
  - Cell with lowest maximum gradient causes the performance limitation
- In principle, can extract information about all the (pairs of) cells, but this possibility has not been fully exploited
  - Quench location is “easy” to detect; field emission source more difficult
- Performed during small fraction of cavity tests (I know of 5)
  - LHe and/or time limitation (or not high priority)
  - Lack of variable coupler
- Have been extremely useful for vendor qualification tests in which (eventually) well located hard quenches occurred
- Should be performed during every vertical test for maximum value

Mode Measurement Example

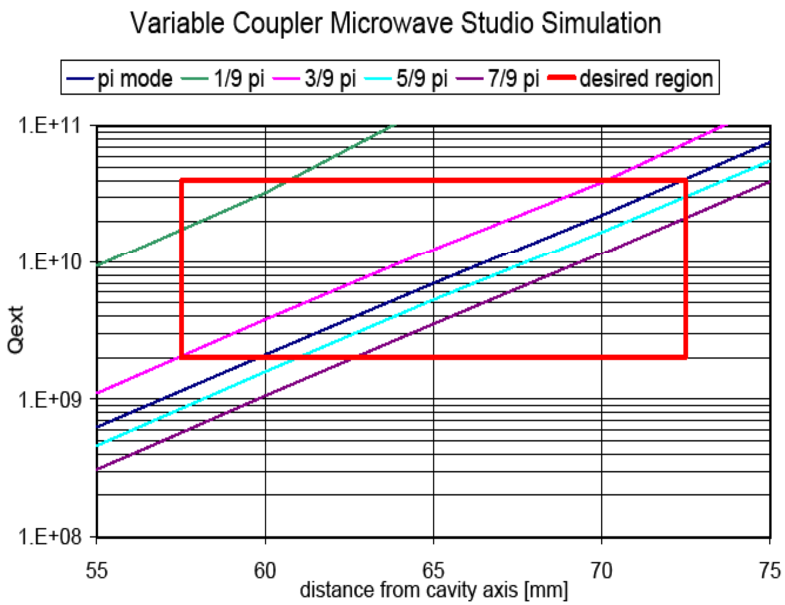


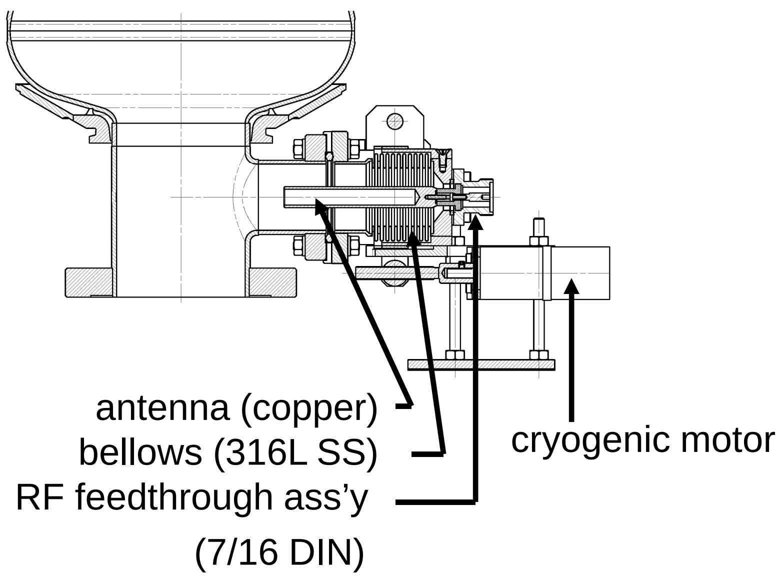


AES1 test at Fermilab

- Mode measurements very useful to find quench location
  - Cell limitation found at JLab to be 3 or 7
  - Cell 3 found to host quench site after several tests using fast thermometry
- Using fixed coupler
- Field emission turned on for gradients above 15 MV/m, only reachable in $7\pi/9$ mode

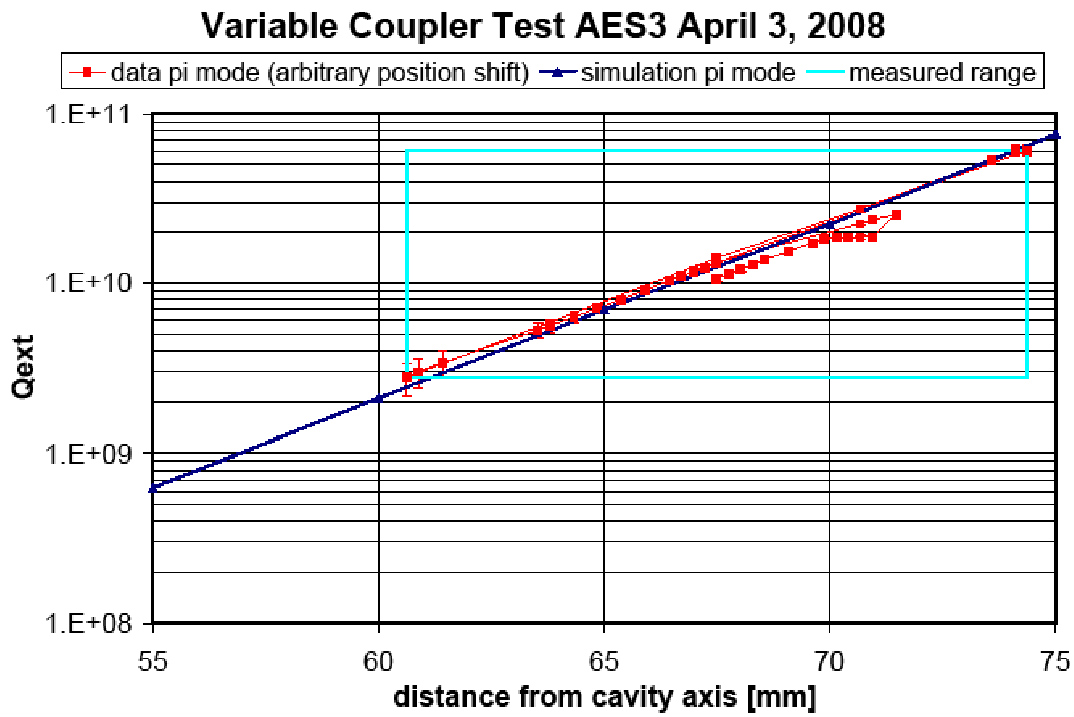
Fermilab: Variable Coupler





- Purpose: Always keep cavity critically coupled
  - Facilitates mode measurements
  - Reduces measurement errors
  - Reduces standing waves in cables which can damage them in case of high power
- Design parameters
  - Mount coupler to standard input coupler port, to save vertical space in cryostat
  - 2×10^9 < Qext < 4×10^{10}
    - From DESY vertical test experience
  - Cryogenic motor submerged in liquid helium bath, to save instrumentation space at cryostat top plate
  - Simple & small movement mechanism

Fermilab: Variable Coupler Performance



- Antenna distance from cavity axis inferred from simulation
  - Shape of simulation and data agree very well
- Measured range $2.8\times10^9 < Q_{ext} < 6\times10^{10}$
  - Design range: $2\times10^9 < Q_{ext} < 4\times10^{10}$
- Measured range 60.62 mm to 74.38 mm (ΔR = 13.8 mm)
  - Design range: ΔR = 15 mm

Summary/Conclusions

- Substantial progress on S0 (9-cell Tesla-style) cavity tests in Americas region 2006-today
  - Moving toward common process/test requirements
- Variety of cavity test goals
  - Cavity processing studies (Cornell, JLab)
  - Cavity vendor qualification (JLab, FNAL)
  - “Tight loop” verification of process for qualified vendor (JLab)
  - Diagnostic instrumentation development (JLab, Cornell, FNAL)
    - Optical inspection, 2^{nd} sound quench location, variable coupler
    - New thermometry mapping systems are being developed at FNAL, Cornell, JLab
- Mode measurements coupled with thermometry or 2^{nd} sound detectors (and subsequent optical inspection) have been useful for understanding cavity behavior
  - Should be performed for every vertical test, to optimize understanding of cavity behavior for each test, and gather statistics