Latest 9-Cell Cavity Test Results from FNAL

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Fermilab

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Introduction

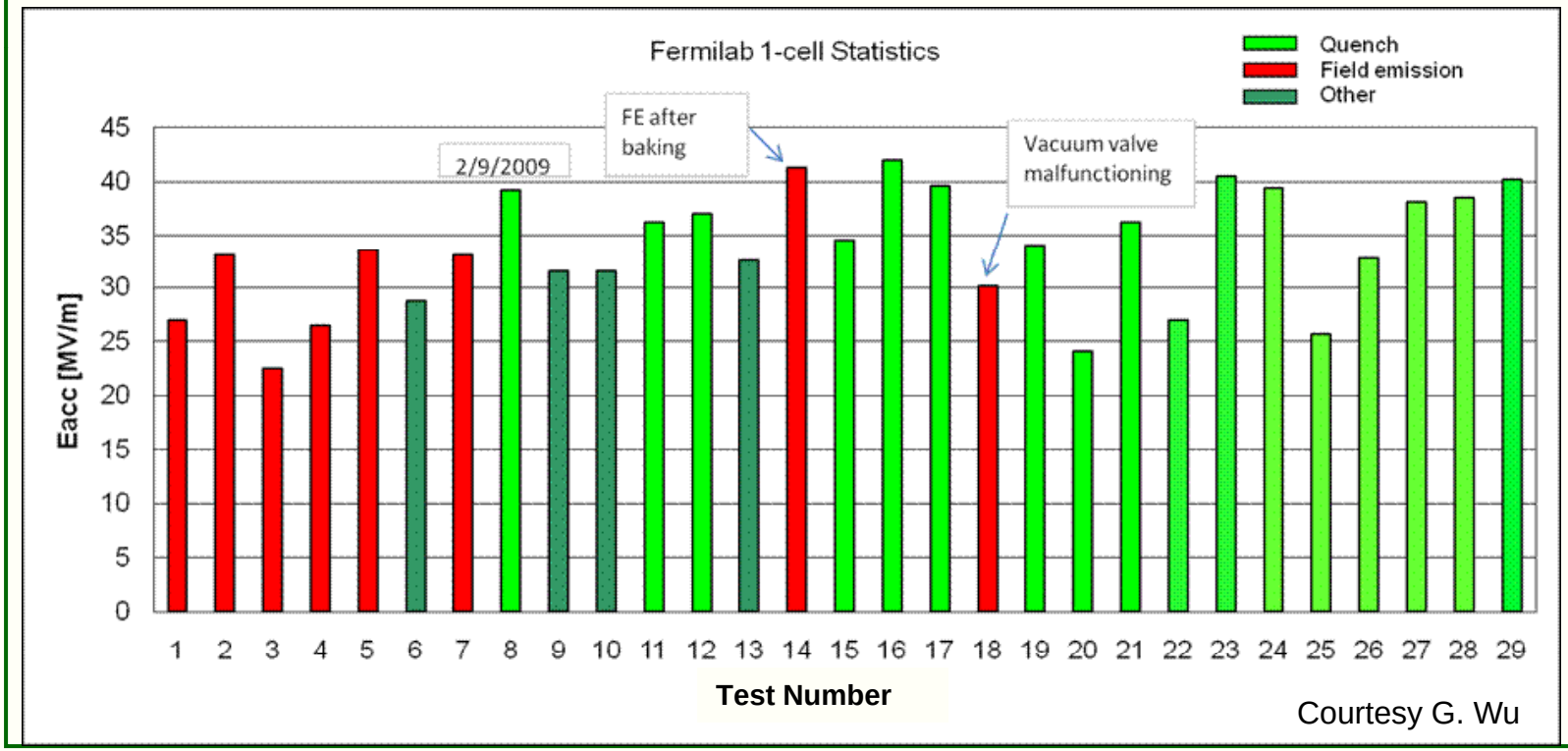
Will discuss 3 sets of 9-cell cavity test efforts :

- **Testing of cavities in support of EP system commissioning and process development**
- **Testing of dressed cavities in support of S1 Global cryomodule**
- **Testing of repaired 9-cell cavity**

Cavity Tests – EP System Commissioning

EP and HPR systems at the joint FNAL/ANL facility were first commissioned using single-cell cavities during 1st half of CY09.

Facility now capable of routinely producing single cell cavities that reach 30+ MV/m and are FE-free.



Courtesy G. Wu

Cavity Tests – EP System Commissioning

After EP & HPR systems commissioned w/single cells, begin 9-cell EP commissioning.

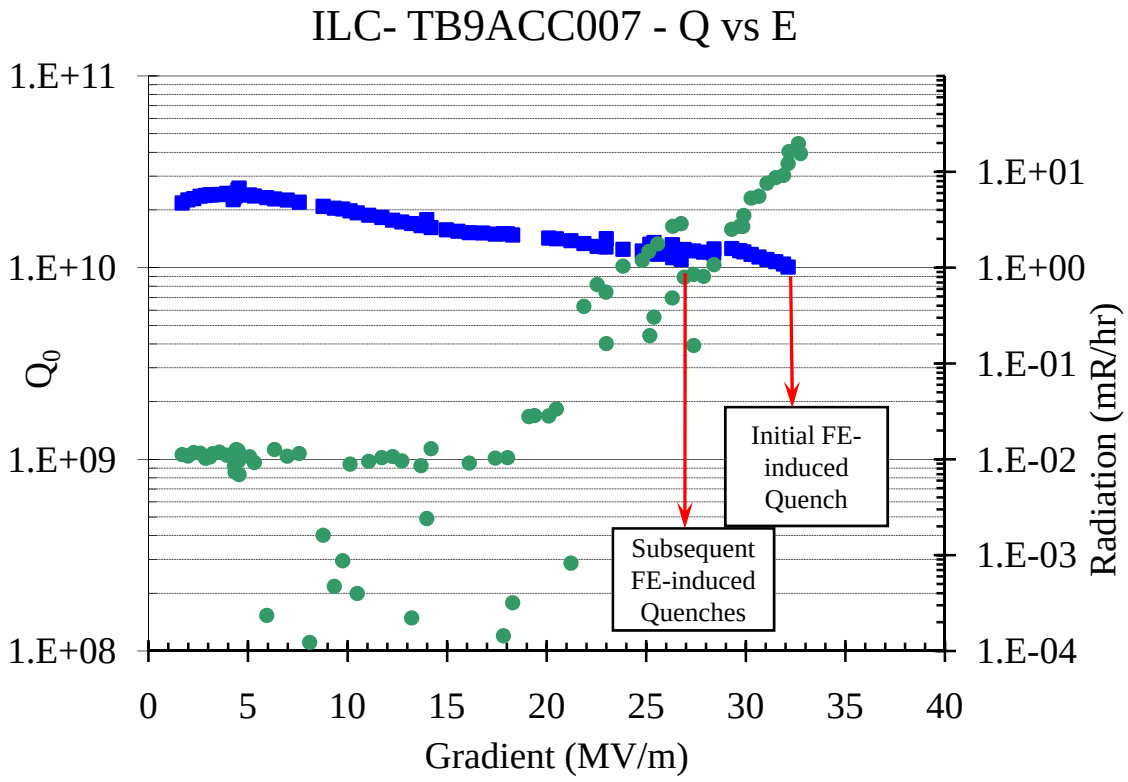
Cavity TB9ACC007 was initially processed/ tested several times at JLab, reaching gradients from 29-42 MV/m, with most recent result being 32 MV/m.

Then used for 1st EP process (9-cell) at FNAL/ANL facility, w/ subsequent HPR/test at JLab. Limited to 22 MV/m (Q-slope). Returned to FNAL.

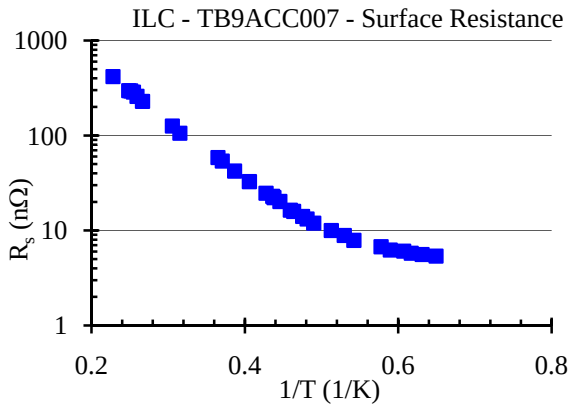
Performed moderate (~50μm) EP, followed by standard HPR, assy, then 120°C bake-out for 46hrs.

Tested at FNAL VTS at 2.0K.

TB9ACC007



Cavity low field
$Q_0 = 2.3 \times 10^{10}$



Residual surface resistance = 5.4 nΩ

Initial FE onset at 19.4 MV/m. Cavity initially reached 32.7MV/m (FE-induced quench), then FE onset earlier (16MV/m) and cavity now limited to 26MV/m.

TB9ACC007

Field emitter activity at high field (33 MV/m) led to reduced cavity maximum gradient and earlier FE onset.

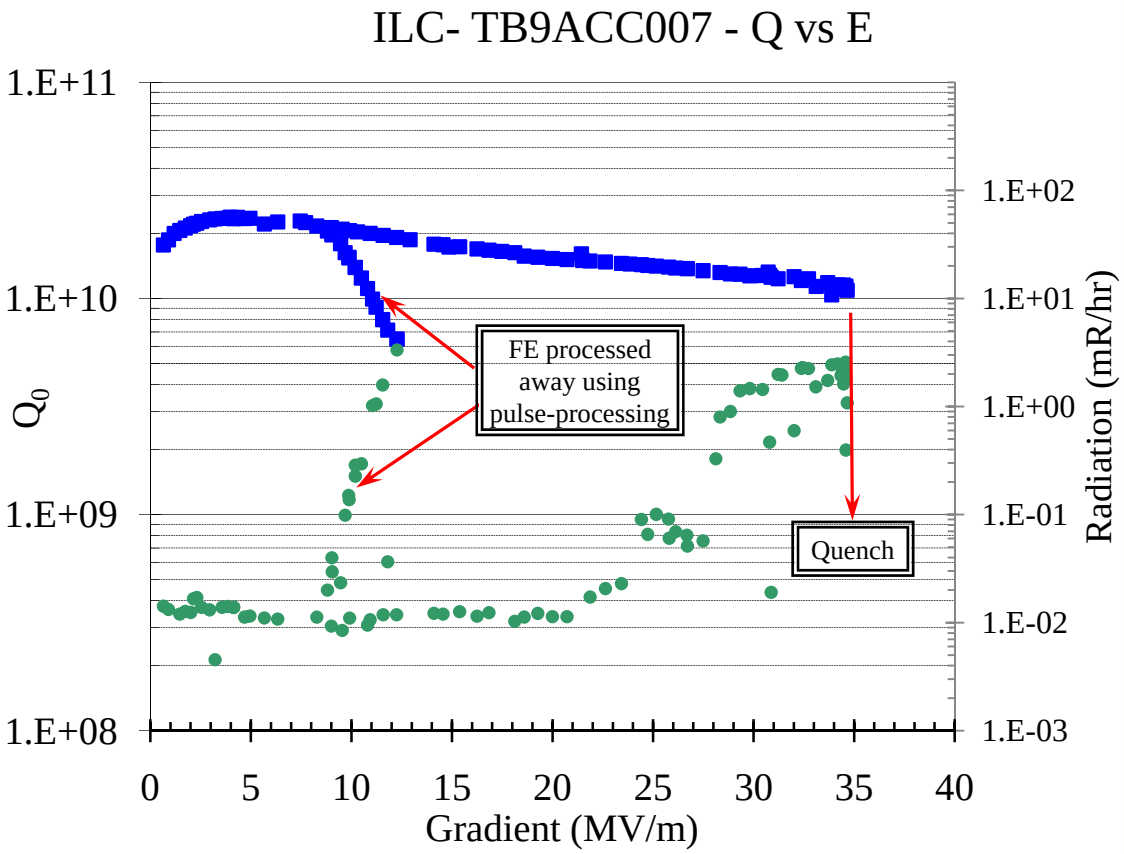
Performed additional HPR, and retested cavity. Cavity again limited to 26MV/m, but with much lower FE (5 x 10^{-2} mR/hr vs 20mR/hr during last test), and higher FE onset (24MV/m vs 16MV/m).

Mode measurements show hard quench in cells 2/8 ($3\pi/9$ mode), with no FE.

Performance degradation thought to be due to particle liberated during field-emitter activation during first test, which ended up on the equator (high B field region), and becomes normal, leading to a quench. Subsequent test with thermometry confirmed quench hot-spot on cell #8 equator.

Cavity then received additional light EP and HPR, before re-test.

TB9ACC007



Cavity low field
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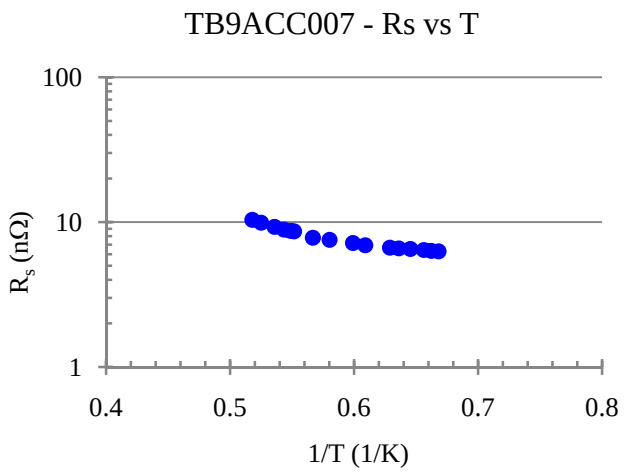


Residual surface resistance = 5.9 nΩ

Initial FE onset at 9 MV/m, but quickly processed away using pulse processing (low power). Cavity quenched at 34.6 MV/m. Mode measurements indicate (hard) quenches in cells 1, 4, 6, & 9 at 34MV/m. Cavity set aside for potential future CM use

Cavity Tests – EP System Commissioning

Cavity TB9ACC017 - first cavity to be (almost) exclusively processed at FNAL .

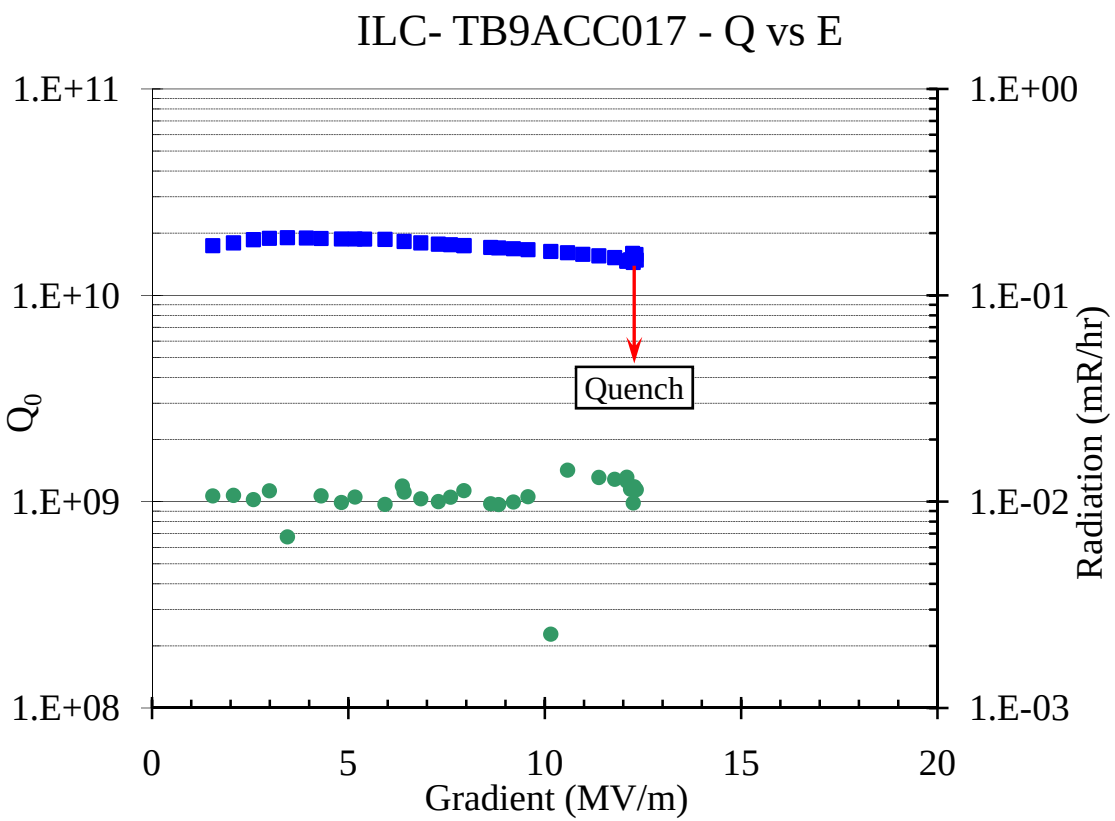
Received bulk (150μm) EP at FNAL/ANL facility, then sent to JLab for heat treatment (600°C).

Upon return to FNAL, received light (15-20μm) EP, ultrasonic rinsing, HPR at FNAL/ANL facility.

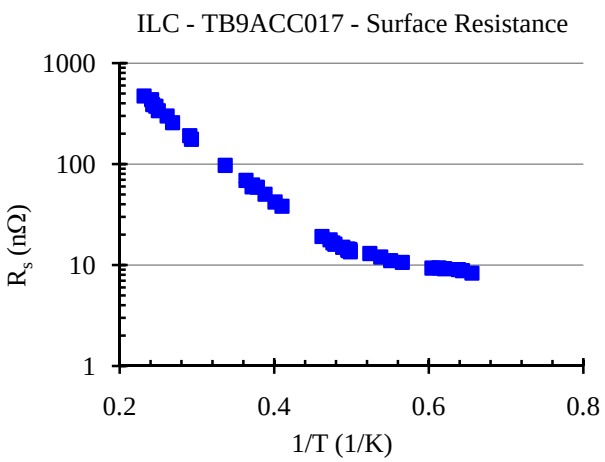
Cavity then received optical inspection, tuning, and straightening.

Performed 120°C bake-out for 78hrs at IB1 before being tested at FNAL VTS at 2.0K.

TB9ACC017



Cavity low field
$Q_0 = 1.9 \times 10^{10}$

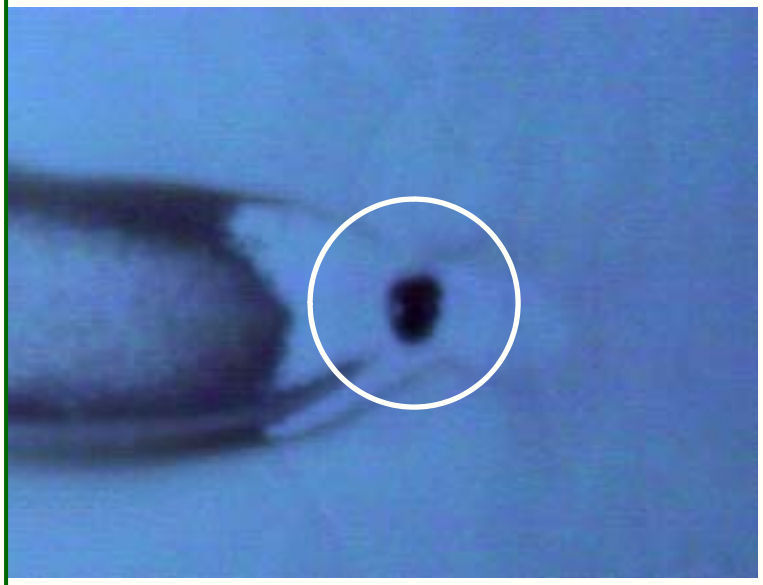


Residual surface resistance = 8.1 nΩ

Cavity quenched (hard) at 12.3 MV/m, no FE. Mode measurements indicated cells 4/6 responsible for quench limit. Re-test w/ thermometry indicated a hot spot on the equator of cell #4.

TB9ACC017 – Optical Inspection Results

Optical inspection – cell #4 equator, correlated with quench (heating) location



Before EP ~190μm diameter

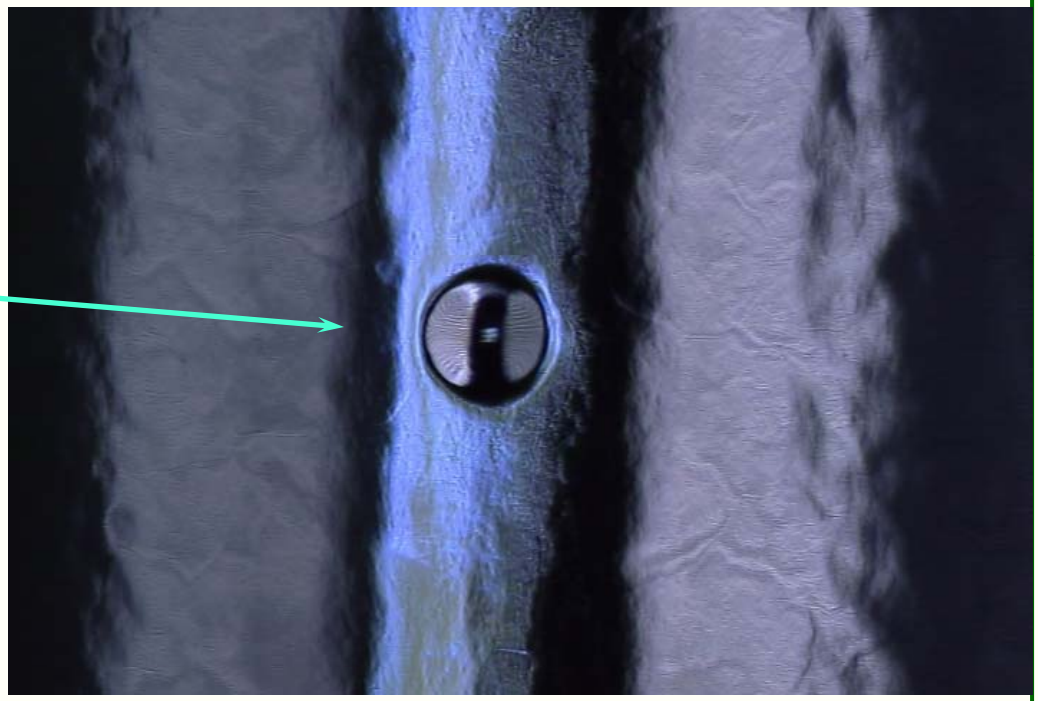
After EP ~ 230μm diameter

TB9ACC017 – Optical Inspection Results

Optical inspection – iris between cells 4 & 5

Nearly hemi-spherical defect on iris weld.

Diameter = 750μm (0.75mm)



The pits on TB9ACC017 will be studied using the molding/replica technique, and then cavity repair will be attempted using the laser re-melting technique.

Cavity Tests - Dressed Cavities for S1 Global

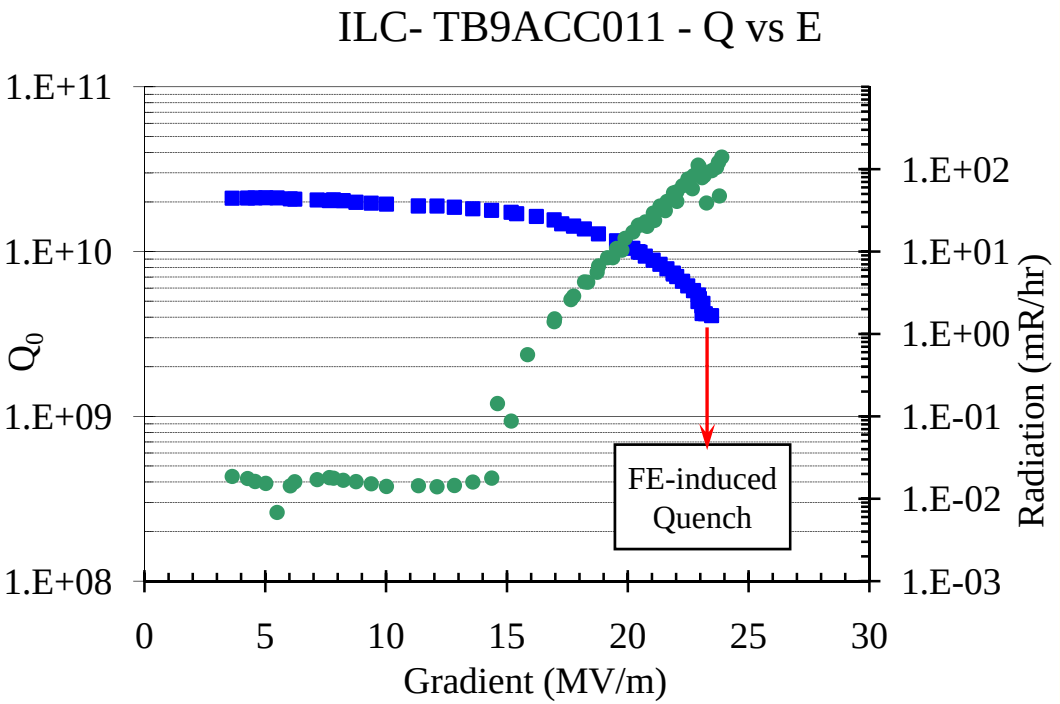
Two dressed cavities were to be supplied by FNAL for the S1-Global CM effort – TB9ACC011 and TB9AES002 chosen.

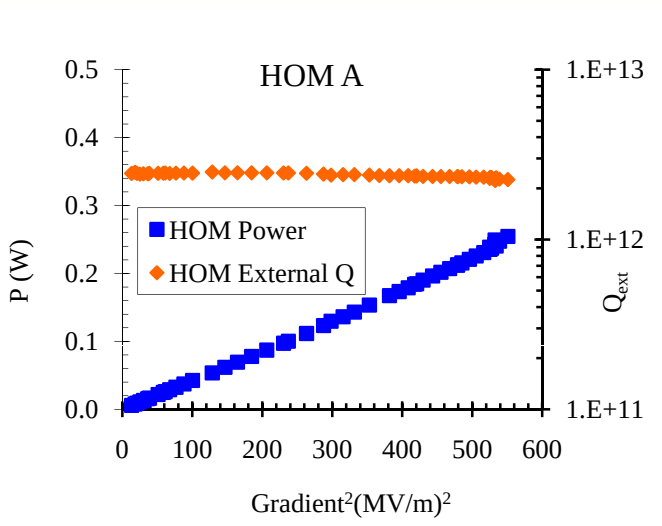
Both had previously been processed and tested at JLab, reaching 38MV/m (TB9ACC011) and 33MV/m (TB9AES002).

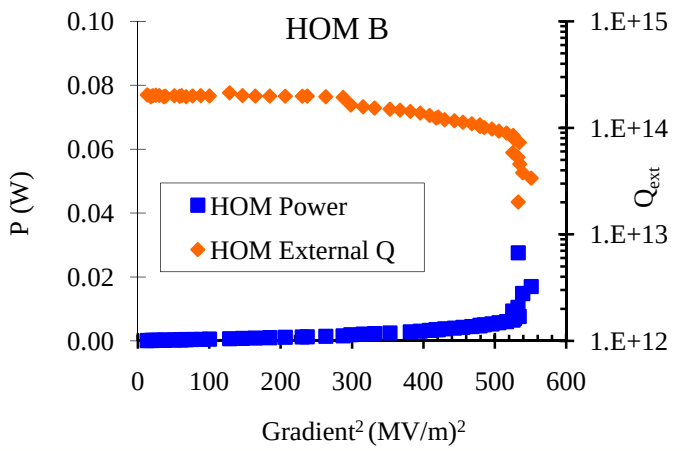
Cavities had He vessels welded on, then US cleaning, HPR, and assembly for vertical test.

HOM couplers were also installed and HOM filters tuned.

TB9ACC011

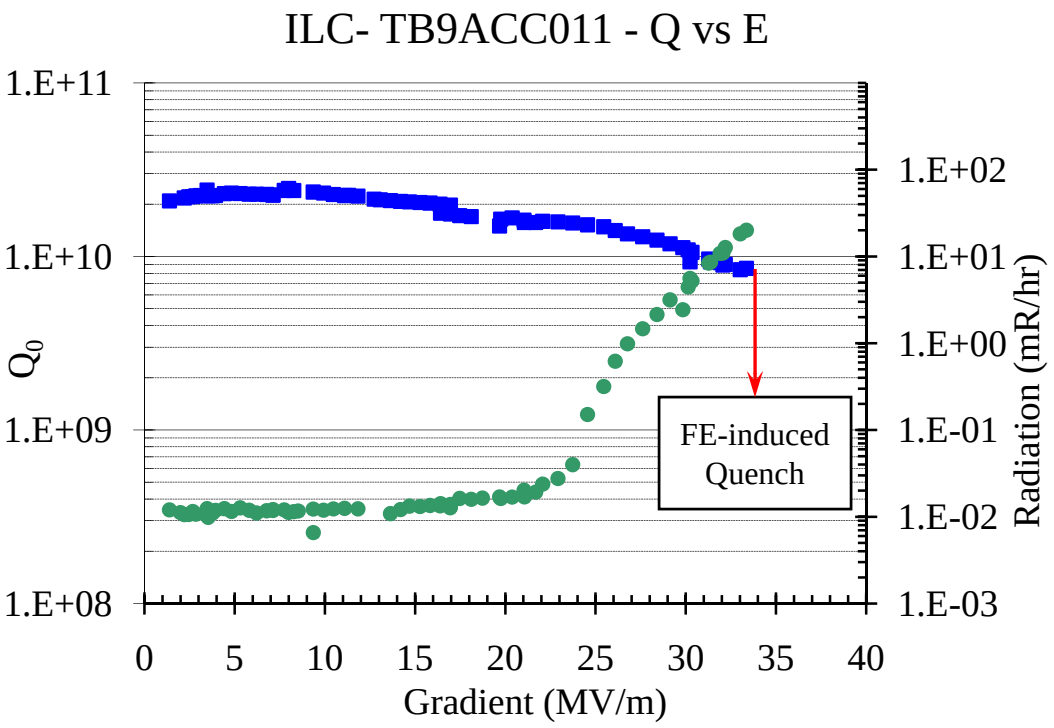


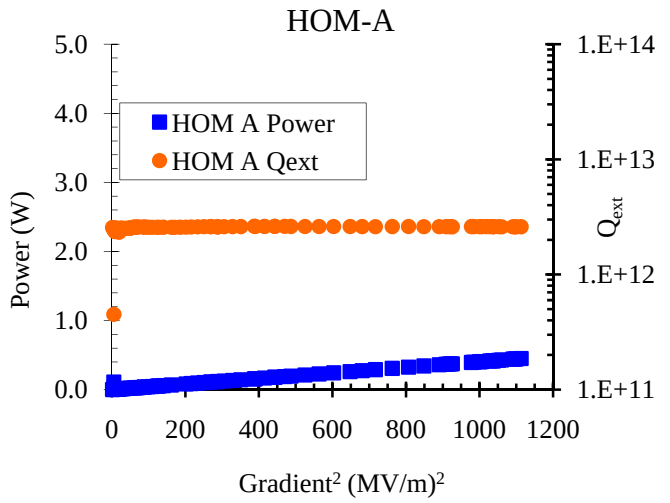


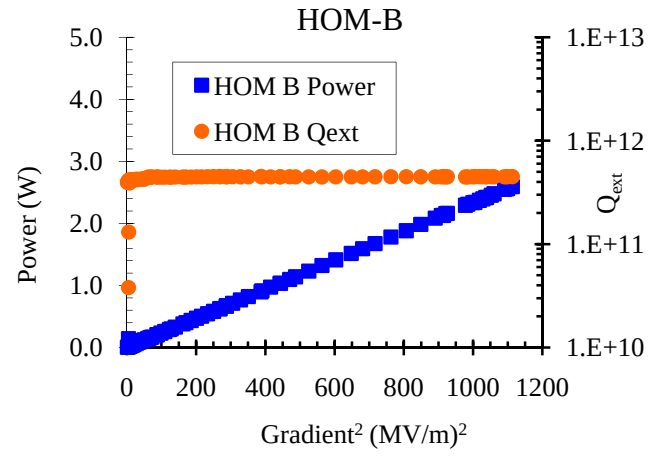


Cavity reached 23MV/m, limited by FE; onset of FE 15MV/m. Low field $Q_0 = 2.1 \times 10^{10}$. HOM-A power and Q_{ext} reasonable and uniform, no anomalous heating observed. HOM-B had cable problems (seen during calibration also), leading to unstable measurements. Cavity returned for additional HPR cycles.

TB9ACC011



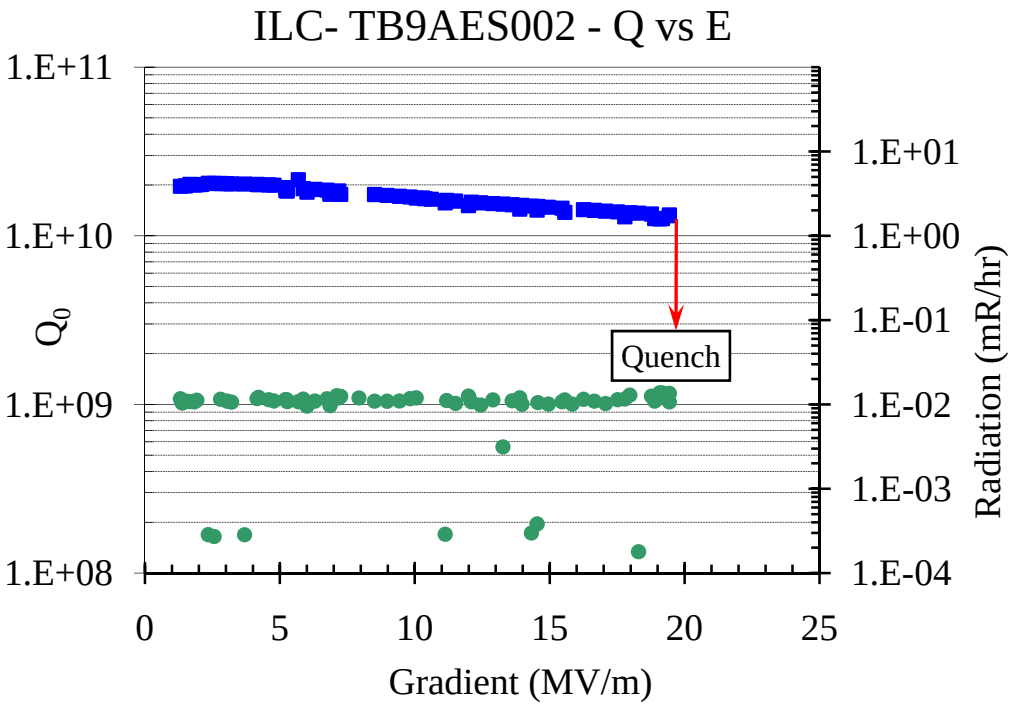


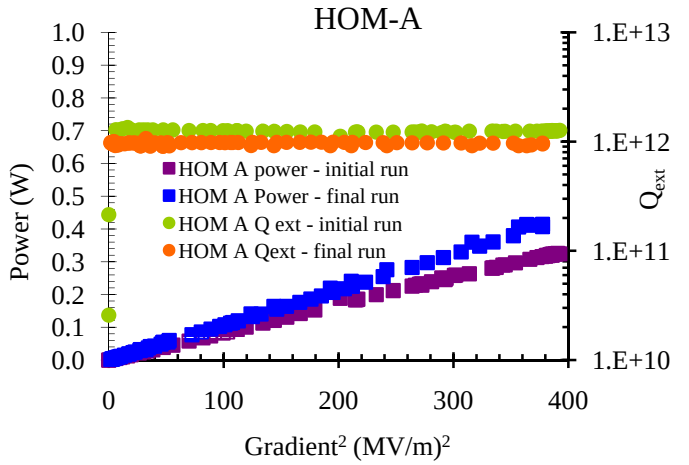


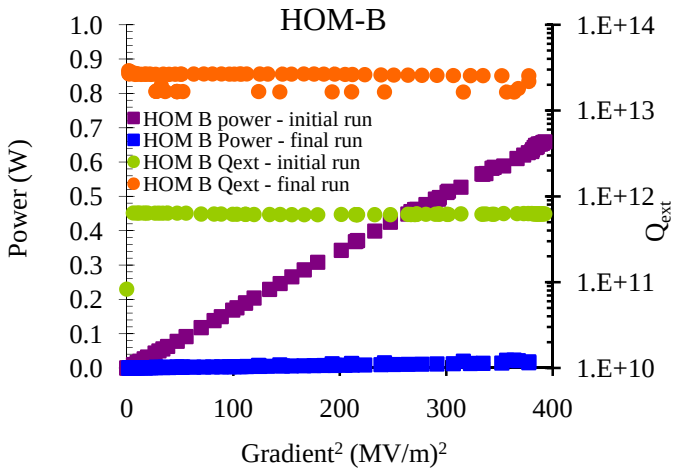
Cavity reached 33.3MV/m, limited by FE; onset of FE now 23MV/m. Low field $Q_0 = 2.1 \times 10^{10}$. Both HOM-A and HOM-B power and Q_{ext} reasonable and uniform, no anomalous heating or degradation observed.

Cavity chosen for use in S1-G CM.

TB9AES002



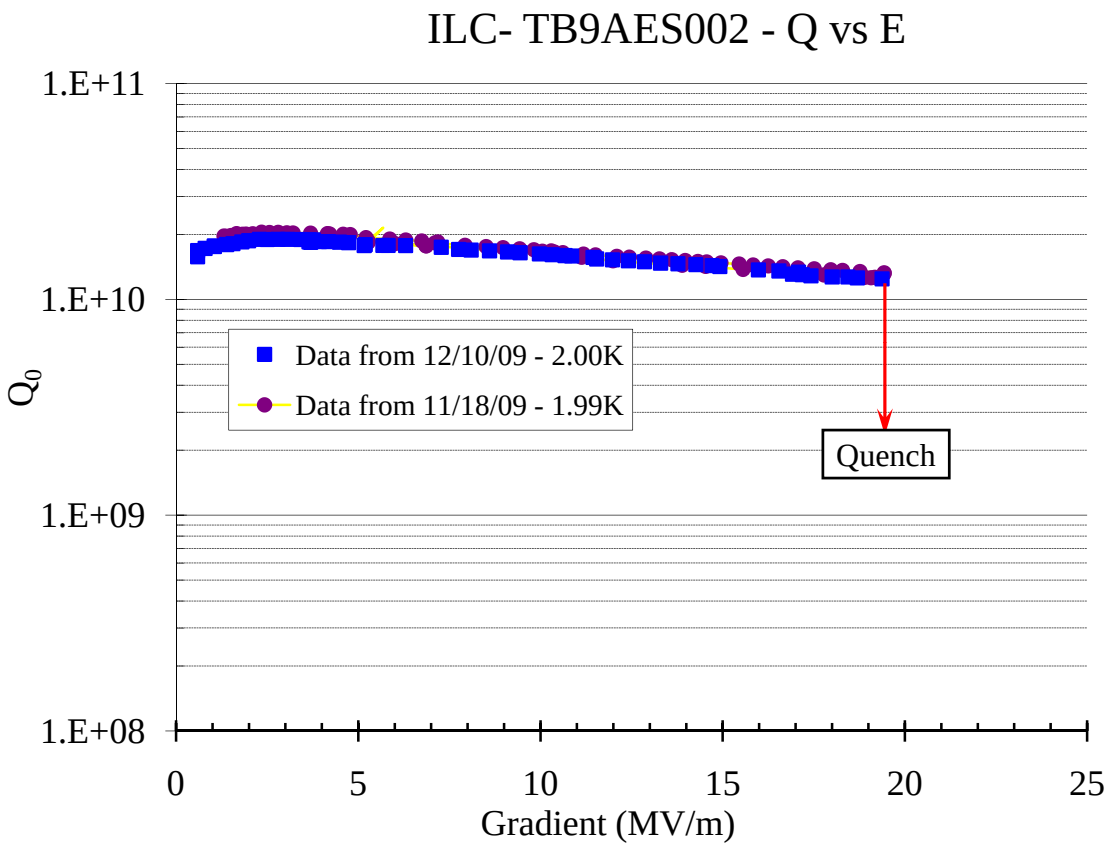




Cavity quench limited to 19.8MV/m, no FE. Low field $Q_0 = 2.1 \times 10^{10}$. HOM-A power and Q_{ext} reasonable and uniform, no anomalous heating or degradation observed. HOM-B experienced signal problem – 20dB attenuator was damaged by high HOM powers during attempt at mode measurements.

Cavity returned for additional HPR (EP not possible).

TB9AES002

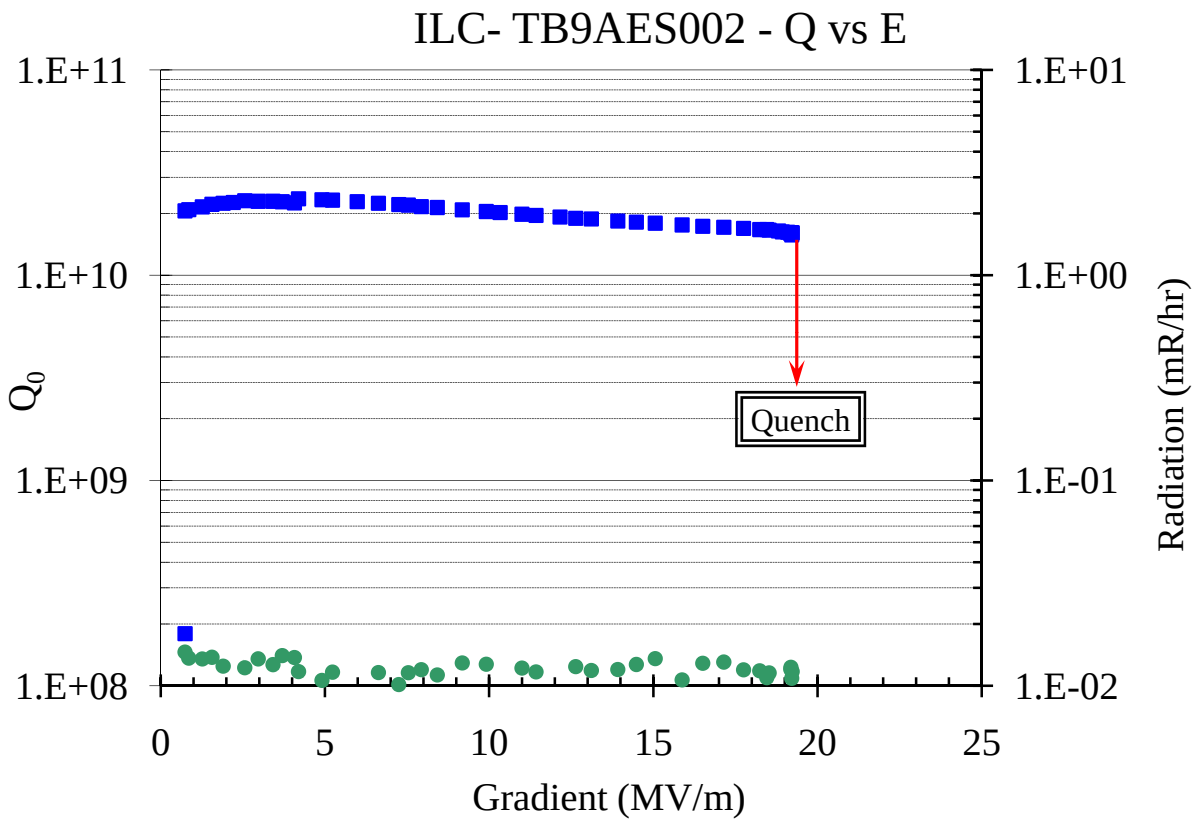


Cavity again quench limited to 19.8MV/m, without FE – identical result as previous test.

HOM probes not connected, in order to eliminate possibility of cavity end-group heating from heat conduction through cables. No effect on performance.

Cavity returned for removal of HOM probes (to allow mode-measurements), no further HPR.

TB9AES002



Cavity re-tested with HOM couplers removed, and once again quench limited to 19.3MV/m, with no FE.

Mode measurements indicate that cell pair 1/9 ($8\pi/9$ mode) quenches at 18.9 MV/m, and cell pair 2/8 ($3\pi/9$ mode) quenches at 19.6 MV/m. Post-test field profile measurements may help disambiguate quench location.

Cavity not used for S1-G CM, TB9AES004 (HTS tested), used instead. TB9AES002 on the R&D path (development of dressed cavity chemical processing capability).

Cavity Tests – Test of KEK Repaired Cavity

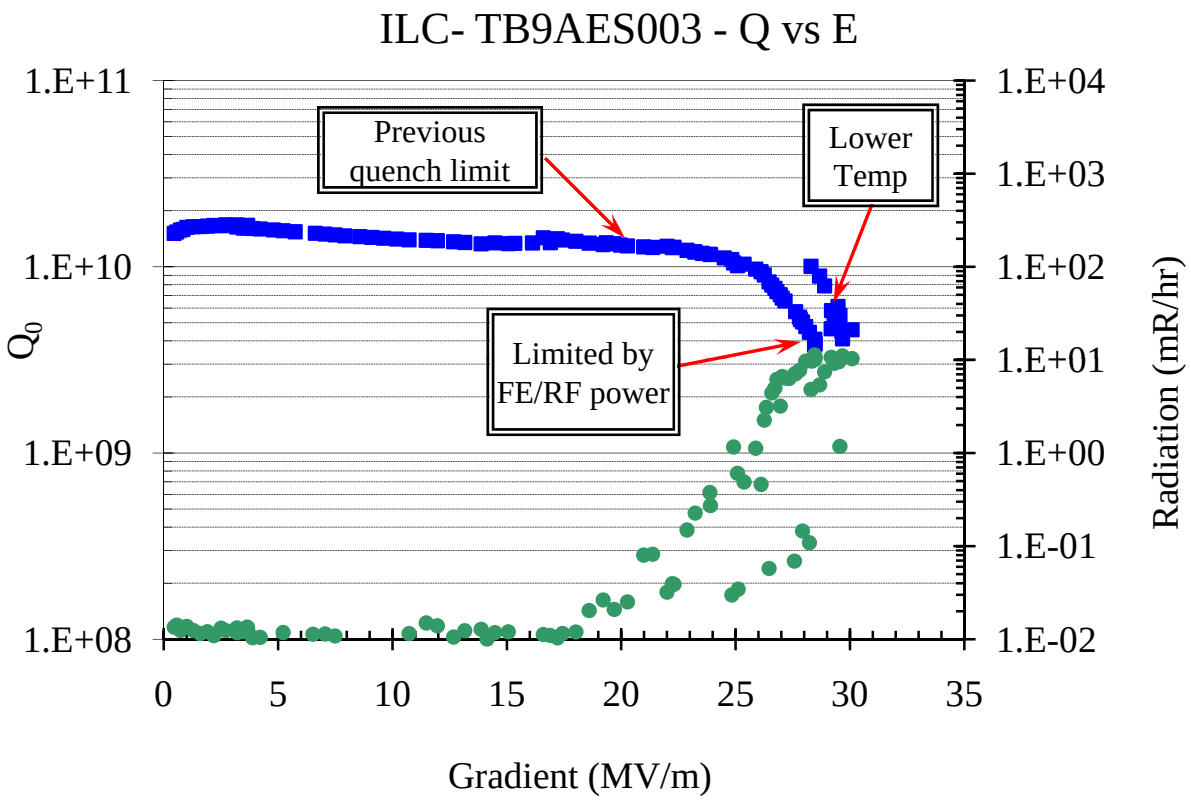
Cavity TB9AES003 (aka AES003) was originally quench limited to 20MV/ during tests at JLab and FNAL. It was then used by LANL for thermometry and optical inspection system development.

Subsequent optical inspection performed at KEK revealed defect at quench origin (determined by thermometry at FNAL).

KEK performed local repair (grinding) and EP/HPR of cavity, then sent to FNAL for test. (See K. Watanabe talk later in this session for complete more details.)

Additional HPR (1x) performed at FNAL due to vacuum leak during shipment. Then vertical test at IB1.

TB9AES003



Cavity limited to 28.5 MV/m, strong FE leading to low-Q, RF power limit. FE onset 18.6 MV/m.

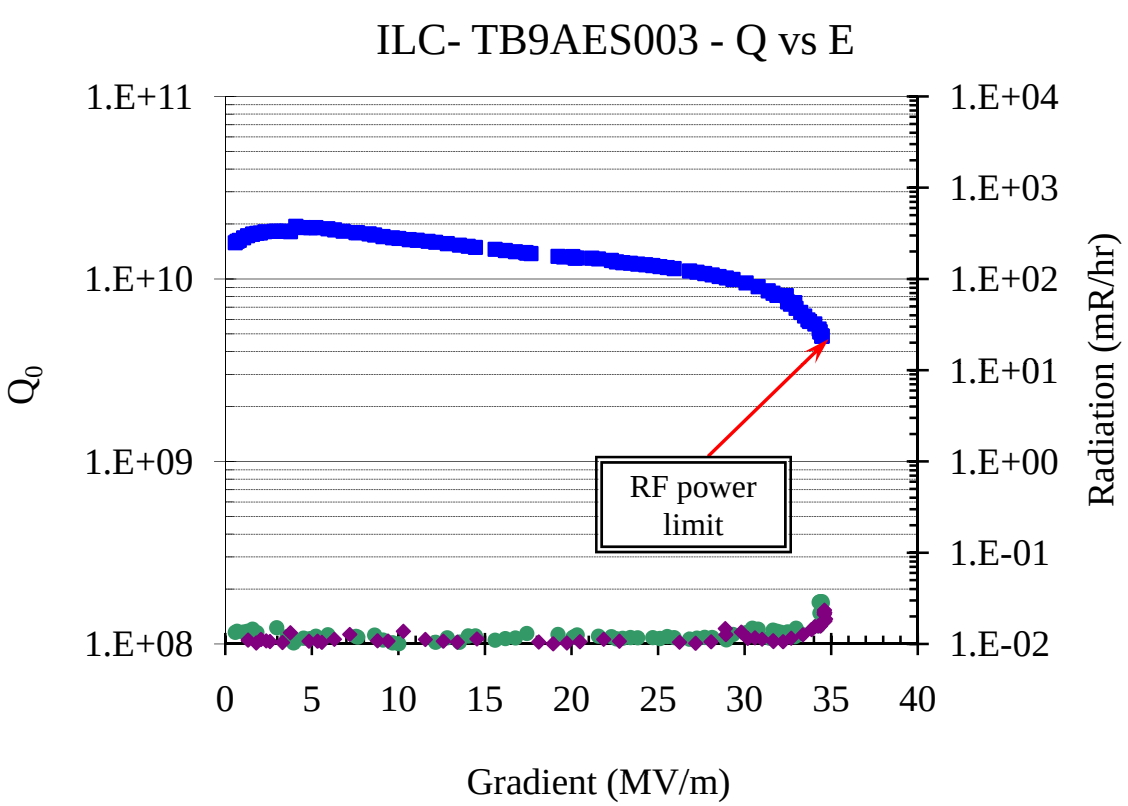
Some pulse-processing attempted, leading to improvement to 30MV/m (at slightly lower bath temp). Again RF power limited due to FE-induced Q-drop.

Thermometry scans of repaired cell showed no hot spots – only general heating due to FE loading.

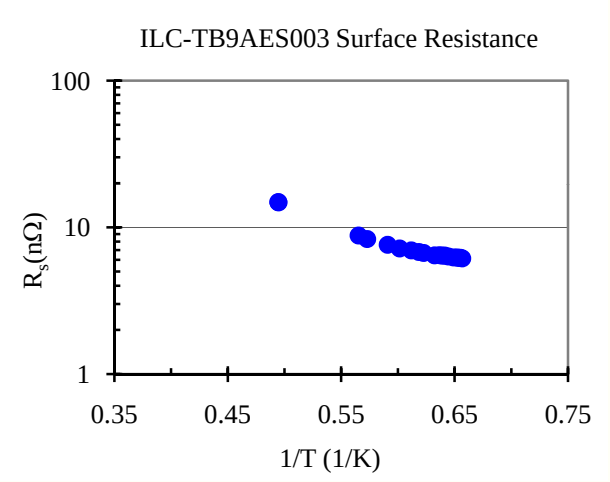
KEK repair technique successfully eliminated defect responsible for 20MV/m quench!

Additional HPR and 120C bake-out (48hrs) pursued to ascertain cavity's true performance limit.

TB9AES003



Cavity low field
$Q_0 = 1.9 \times 10^{10}$



Residual surface resistance = 5.3 nΩ

Cavity reached 34.5MV/m, limited by RF power (Q-drop due to He bath temp increase and some slight FE loading). Additional HPR has significantly reduced FE – cavity now meets ILC specs!

Summary

- The FNAL /ANL EP system is fully commissioned for single cell EP/HPR, and 9-cell HPR, and is nearly commissioned for 9-cell EP.
- Multiple 9-cell cavities that have been (or are about to be) bulk and/or light EP'd at FNAL/ANL will be tested in the coming weeks. We expect this effort to culminate in a fully-commissioned cavity processing facility.
- HPR and vertical test of dressed 9-cell cavities has been successfully performed in support of the SG-1 cryomodule effort.
- KEK repair technique effectively removed 20 MV/m quench-inducing defect, yielding a cavity that meets ILC specs.

Acknowledgments

The work presented is the product of the efforts of many skilled and dedicated people. Thanks go to:

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and our collaborators at JLab and KEK for continued assistance in cavity preparation and processing