Recent 9-Cell Cavity Test Results

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Recent Cavity Test Subjects

TB9RI024 – new cavity fabricated by RI, bulk EP performed at RI, remainder of processing at FNAL/ANL and JLab (800°C H de-gassing). First test w/OST's (second-sound sensors).

TB9RI026 – new cavity fabricated by RI, all processing at FNAL/ANL (bulk and final EP, HPR, etc.) except 800°C H de-gassing at JLab. Cavity sat in the Dewar at 4.5K for ~2 weeks due to cryoplant compressor failure/replacement.

TB9ACC014 – dented cavity, re-test w/second sound sensors and RTD's for quench localization.

TB9AES003 – defect repaired by grinding at KEK, reached 34MV/m after additional HPR, re-test after light EP.

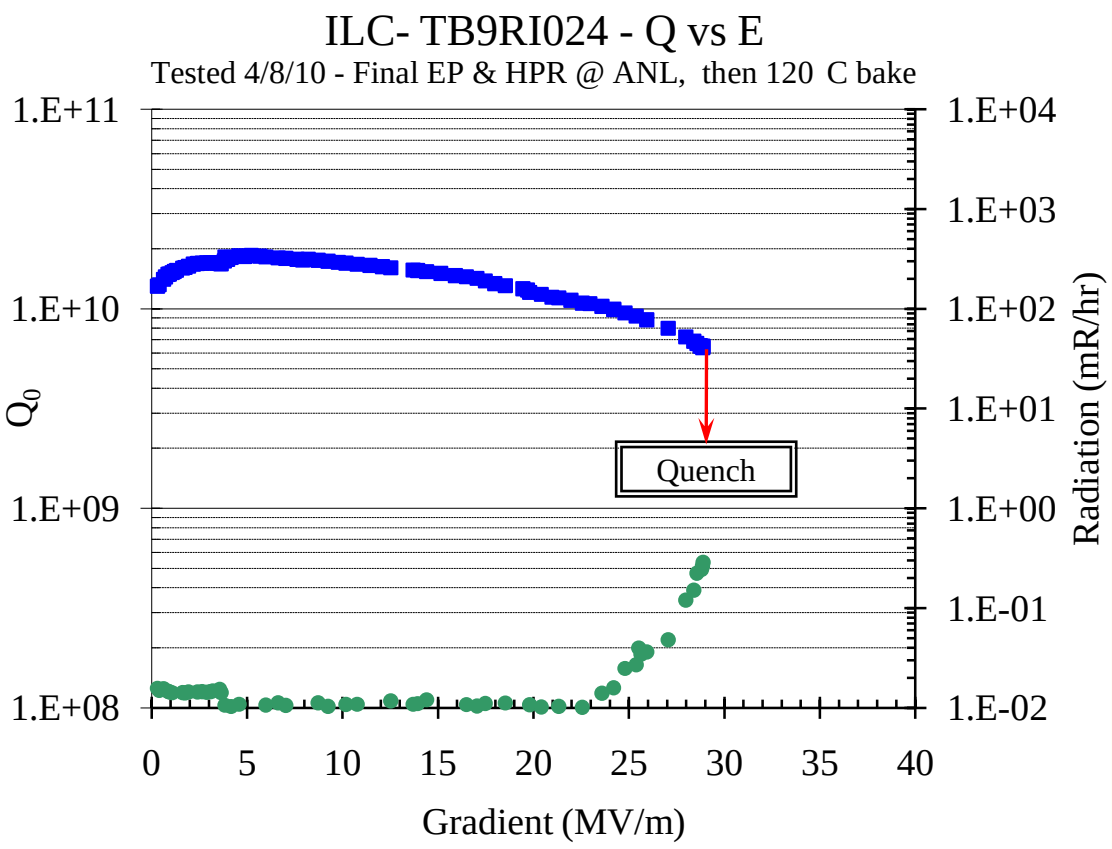
Note: all tests performed at 2K with cavity actively pumped, fixed input coupling (typically between 6×10^9 to 1×10^{10}). Cooldown is fast - 1 to 2 minutes between 140-100K. Full cable calibrations performed for each test – reproducibility of calibration 3-4%.

Cavity History : TB9RI024

- Fabricated by RI
- Bulk (130μm) EP at RI
- Inspections (visual, CMM, RF, optical)
- H de-gassing (800°C, 2 hours) @ JLab
- Light EP (70 minutes), HPR, assy
- 120°C bakeout (63hrs)
- Vertical test

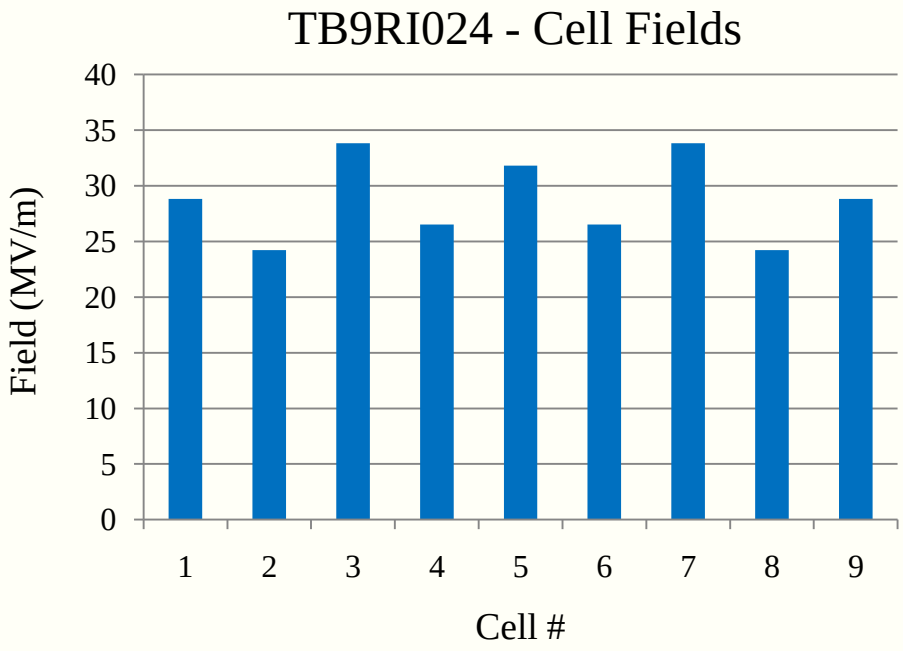
Cavity Performance : TB9RI024

Low field Q_0 = 1.75×10^{10}



Quench at 28.8 MV/m, Q_0 at quench = 6.5×10^9
FE onset at 23.6 MV/m, radiation levels moderate. Fairly strong Q-slope beginning at ~ 20MV/m, even without presence of FE.

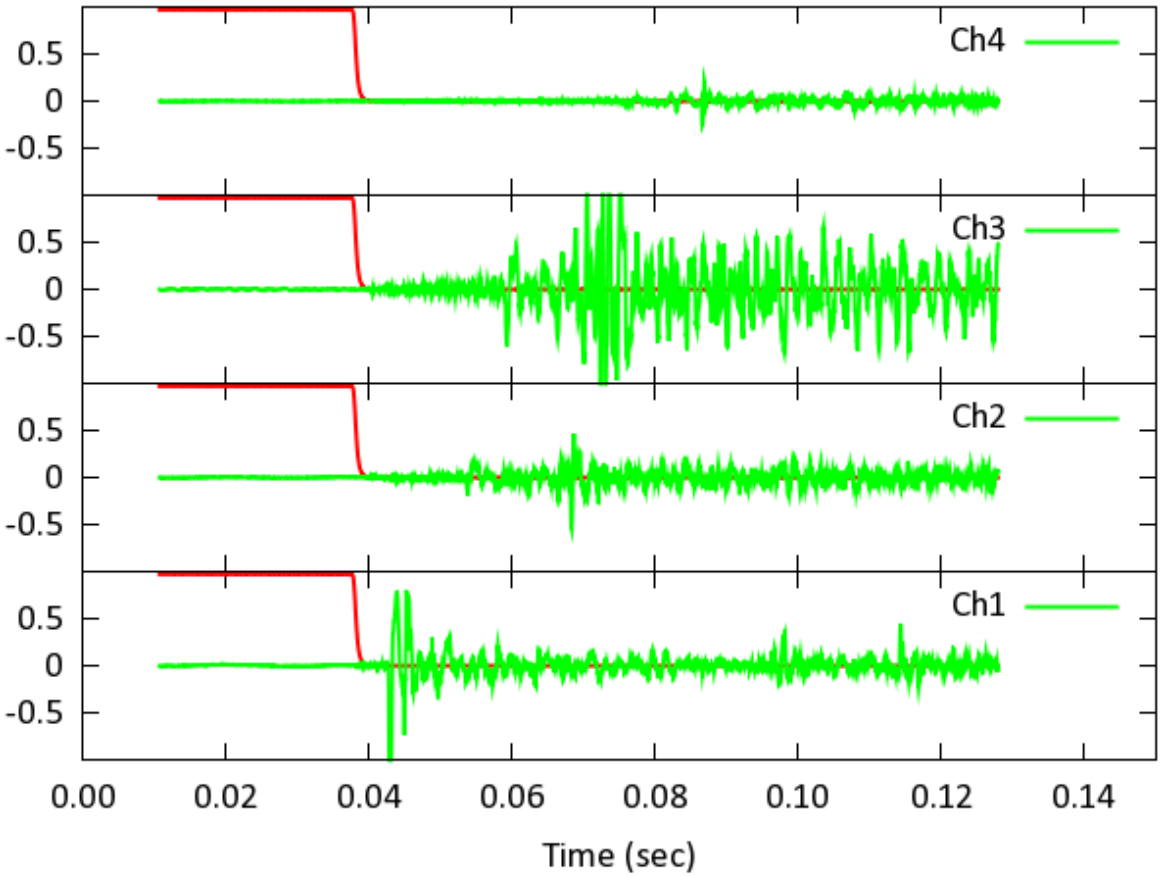
Cavity Performance : TB9RI024



Cells 2/8 lowest performing, quench at 24MV/m.

Four OSTs' (second sound) were mounted on the test stand insert, preliminary data suggest cell #2.

Cavity Performance : TB9RI024



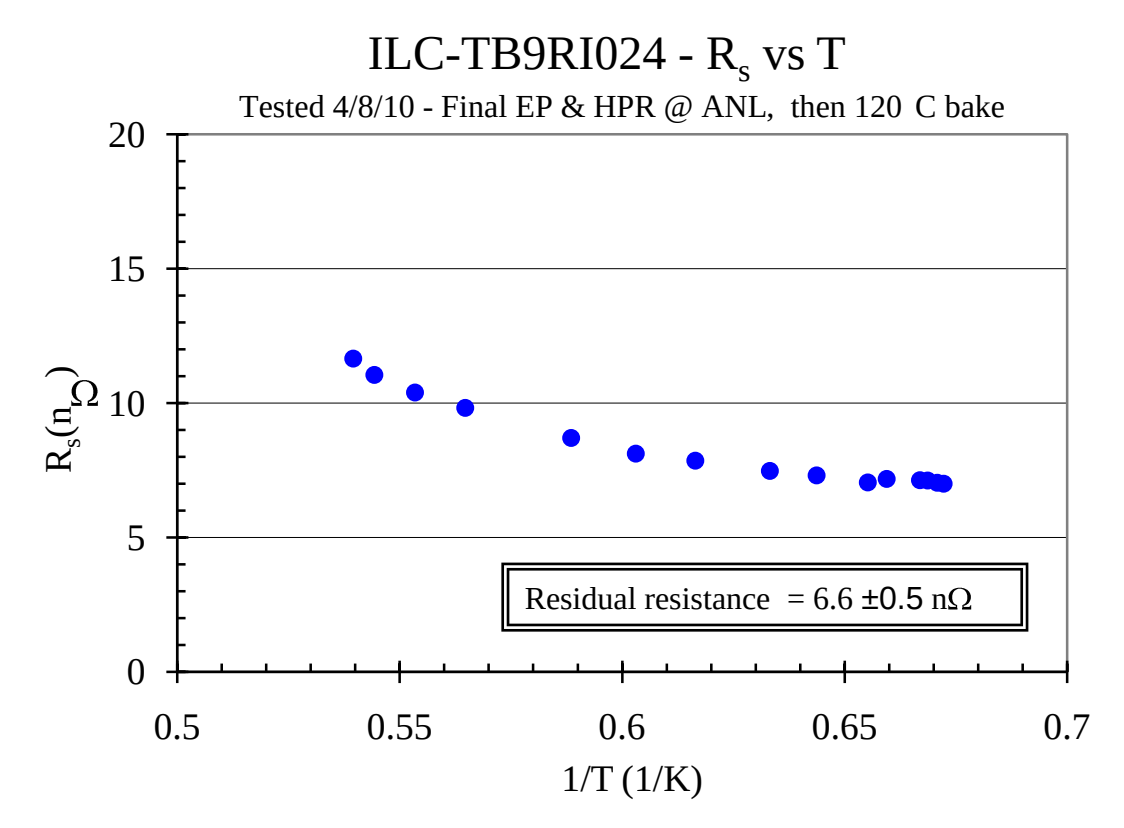
Signals during a quench in the 8π/9 mode from 4 OST's mounted vertically along cavity cage. Channel 1 is at cell #1, channel 4 is at cell #9, channels 2 & 3 are roughly equidistantly placed between them.
Green traces are OST signals, red is the cavity transmitted power.

Data is taken at 1.85K, at 25.6kHz.

Shortest signal delay is on channel 1, indicating that in the 8π/9 mode, cell #1 (rather than cell #9) is the quench source.

(D. Sergatskov)

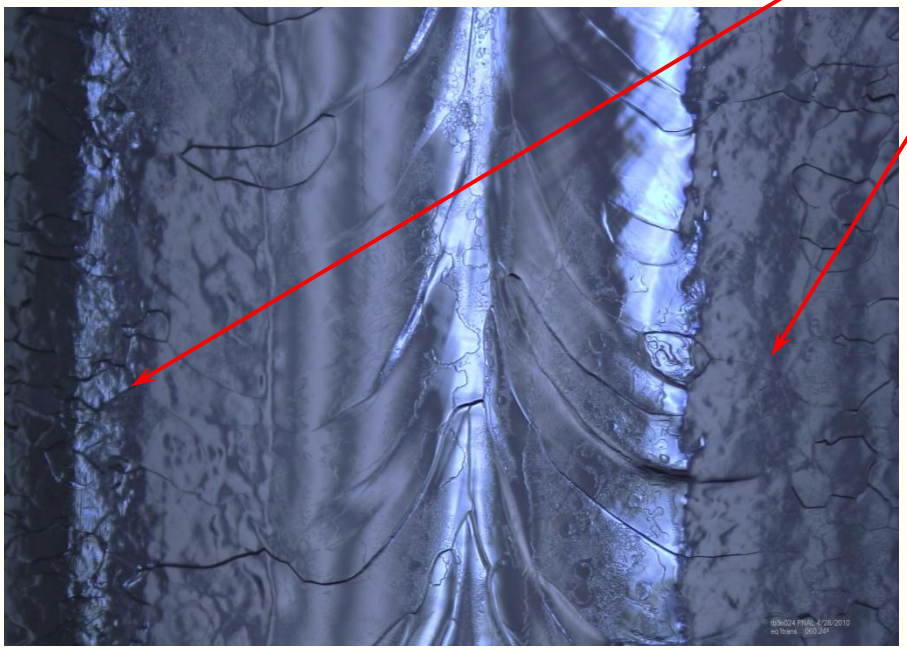
Cavity Performance : TB9RI024



Residual resistance = 6.6 nΩ – somewhat on the high side for EP 9-cell cavities, but a generally good value.

Cavity Performance : TB9RI024

Optical inspection performed after vertical test - no obvious defect observed on cell #2. Overall surface appears “etched” (somewhat high residual surface resistance?).



Next steps :

Light EP (~ 20μm)
HPR/assy
120°C bake
Vertical test

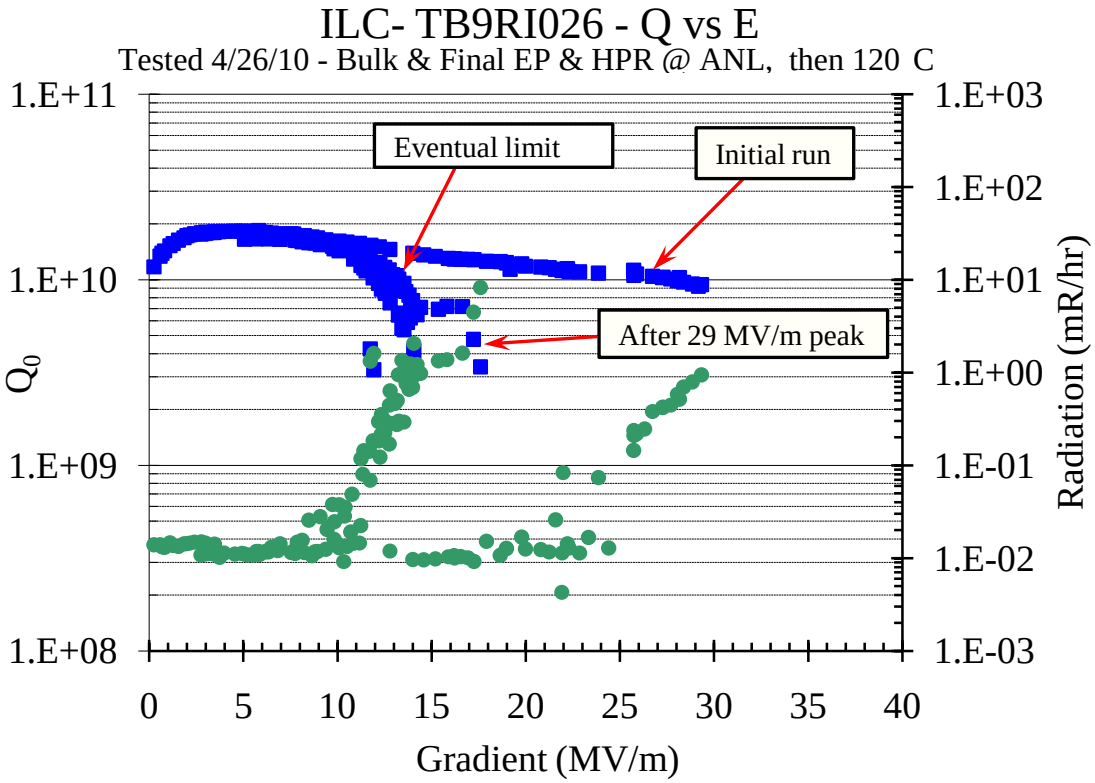
Photo courtesy D. Sergatskov

Cavity History : TB9RI026

- Fabricated by RI
- Inspections (visual, CMM, RF, optical)
- Bulk EP (2x, 80μm + 70μm)
- US cleaning, HPR
- Optical inspection
- H de-gassing (800°C/2 hrs) @ JLab
- Tuning
- Light EP (26μm), HPR, Assy
- 120°C bake, 63 hrs
- Vertical test

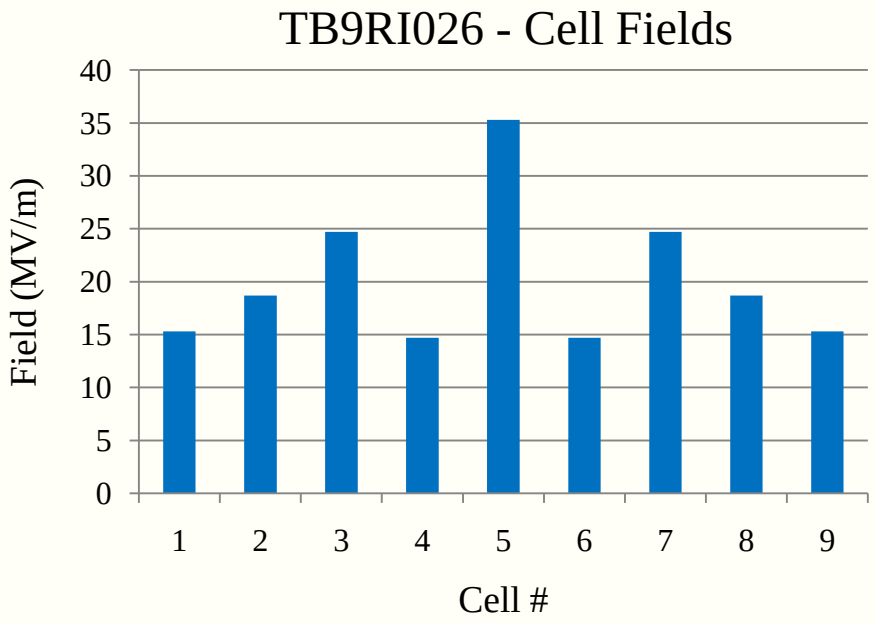
Cavity Performance : TB9RI026

Initial low-field
$Q_0 = 1.8 \times 10^{10}$



Initial FE onset at 25MV/m (after a few “bursts” at 20MV/m), increased with gradient until cavity reached 29MV/m. Quenched from FE at 29MV/m, then much reduced field (16-17MV/m, then down to 14MV/m) and higher FE. Cavity now limited by FE – FE increased sharply while testing.

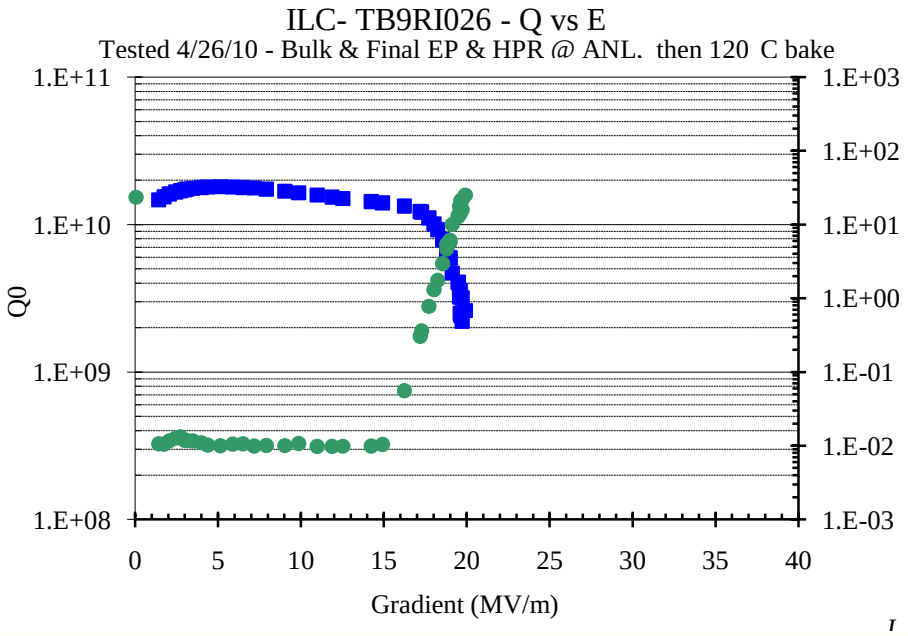
Cavity Performance : TB9RI026

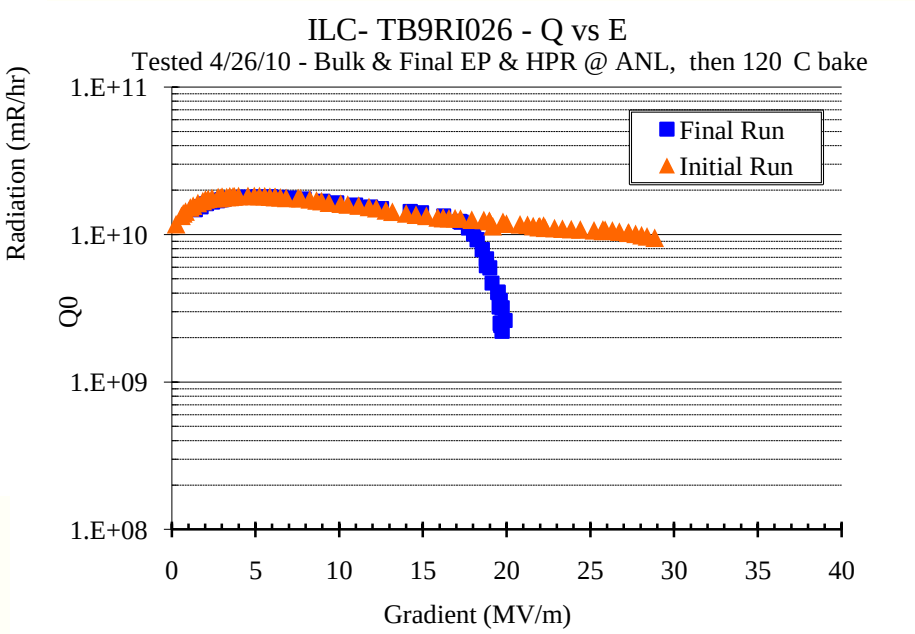


Mode measurements show FE in all modes, least in $\pi/9$ (cell 5 only), highest in $2\pi/9$ and $3\pi/9$ (cell pairs 3/7 and 2/8). Individual mode gradient limits are due to FE behavior, and not intrinsic (defect) limitations.

Some evidence of emitter processing was observed while performing mode measurements so π-mode checked again…

Cavity Performance : TB9RI026



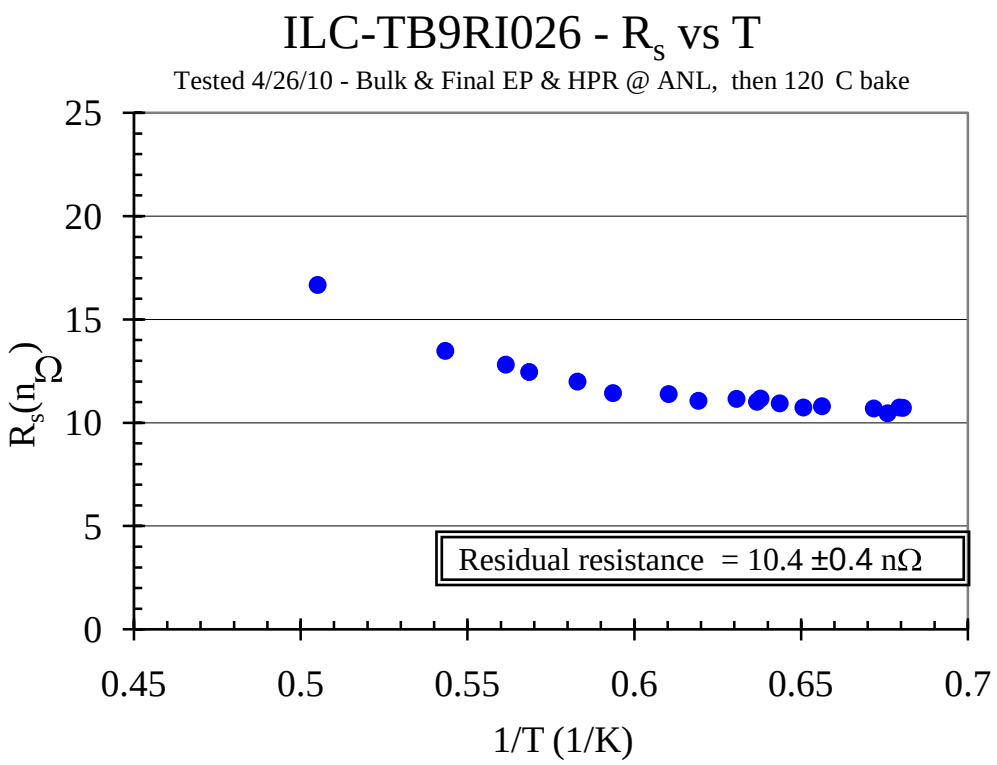


After mode measurements where FE processing was observed, cavity now reached 19.6MV/m in the π-mode (up from 14MV/m, but well below initial run to 29MV/m).

Limited by strong FE/Q-drop.

Comparison of initial (pre strong emitter turn-on) and final (post mode meas.) Q_0 vs E curves. Low-field Q_0 behavior is unchanged, but Q_0 drops sharply at 16MV/m due to strong FE (FE onset 15 MV/m).

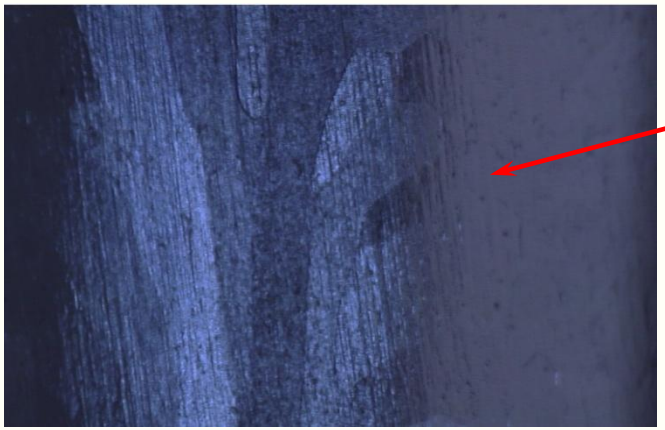
Cavity Performance : TB9RI026



Residual surface resistance = 10.4nΩ – a rather high value compared to typical (good) EP'd 9-cell cavities (4.5 – 6.0 nΩ). Is the degradation due to the activation of a strong emitter, which subsequently globally affects the cavity surface? Q_0 vs T measurements are performed at low fields (3-4 MV/m) where FE is not active, so it does not affect the Q_0 vs T measurement.

Cavity Performance : TB9RI026

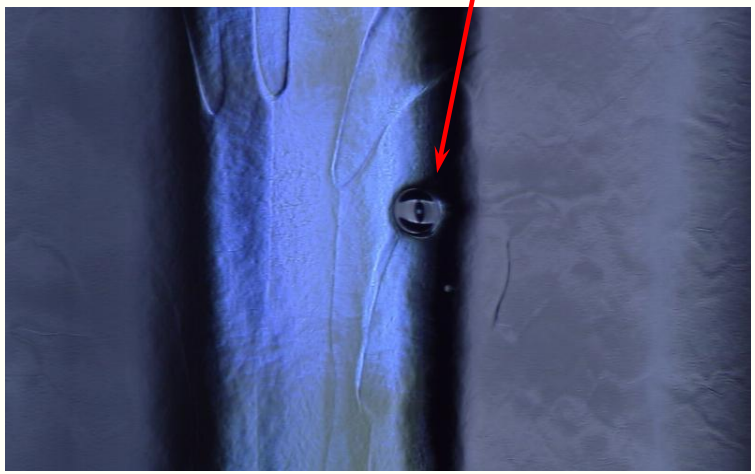
Optical inspections (D. Sergatskov) revealed the evolution (growth) of a feature on the iris between cells 8 &9 :



As received

After 2nd EP
Diameter ~ 350-400 μm

After 1st EP



Cavity Performance : TB9RI026

Cavity is (severely) FE limited. Significant change in performance after reaching 29MV/m implies something drastic happened.

Mode measurements support (not very strongly) problem may be in ends.

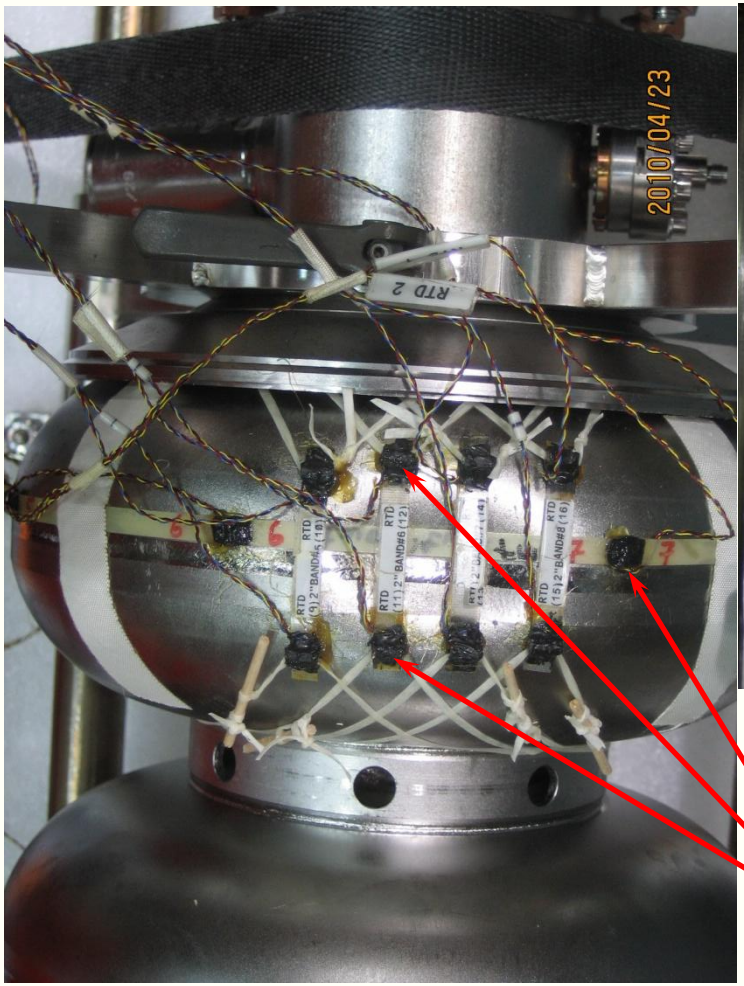
Was the feature on the iris between cells 8 & 9 the source? Did it "turn on" after reaching some threshold, then "process" or evolve into a bad (worse) emitter? Optical inspection to follow vertical test.

The high surface resistivity and severe performance degradation suggest that additional HPR alone will not be sufficient to improve cavity performance significantly. Additional EP is warranted - but EP has been making the defect larger! Wait for optical inspection results.

Cavity History : TB9ACC014

- Cell #9 de-tuned ~20%
- HPR/assy
- Tested 2/10/10
- Reached 29 MV/m, limit appeared to be cell #9 (mode meas & FTS)
- FE present
- Sat at IB1 > 2 mos (under vaccum)
- Prepped for test w/FTS around dent and OST's
- Sat in Dewar cold ~2 weeks (compressor replacement)

Cavity Instrumentation : TB9ACC014



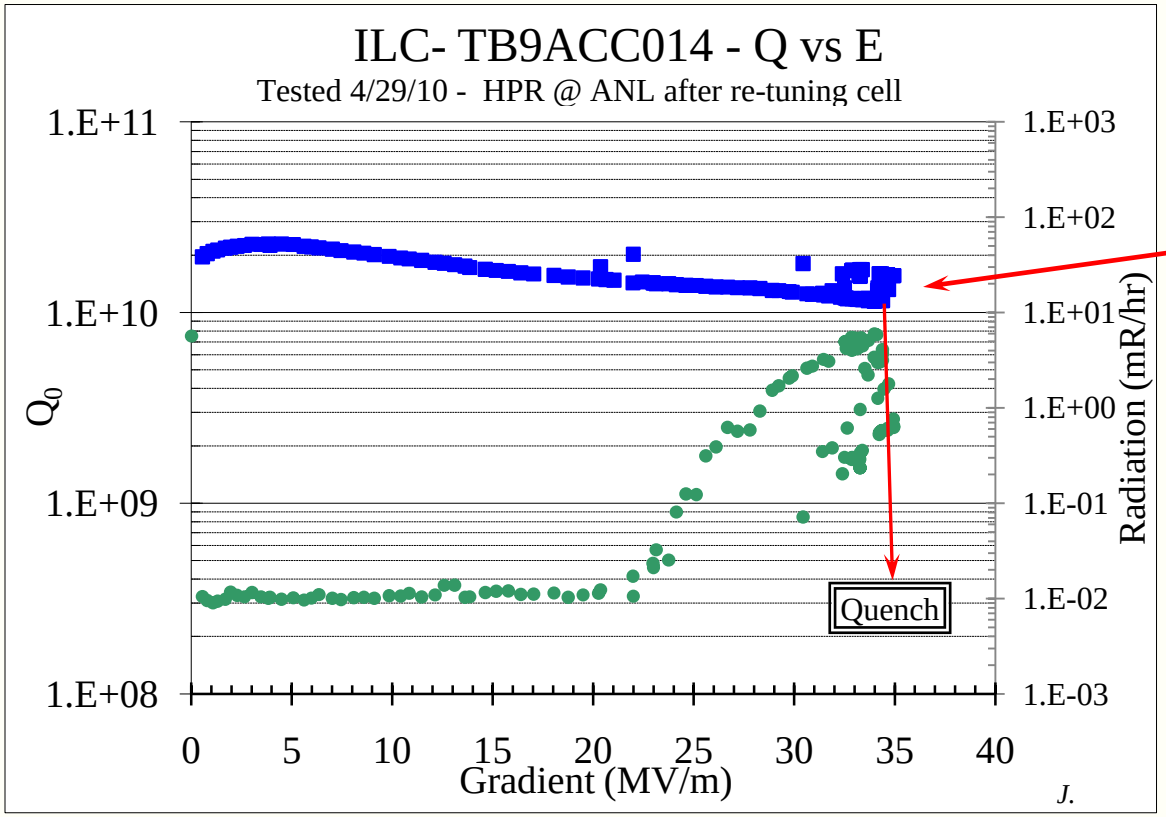
Second sound sensors

RTD's (Cernox)

(D. Sergatskov)

Cavity Performance : TB9ACC014

Low field Q_0 2.3 x 10^{10}

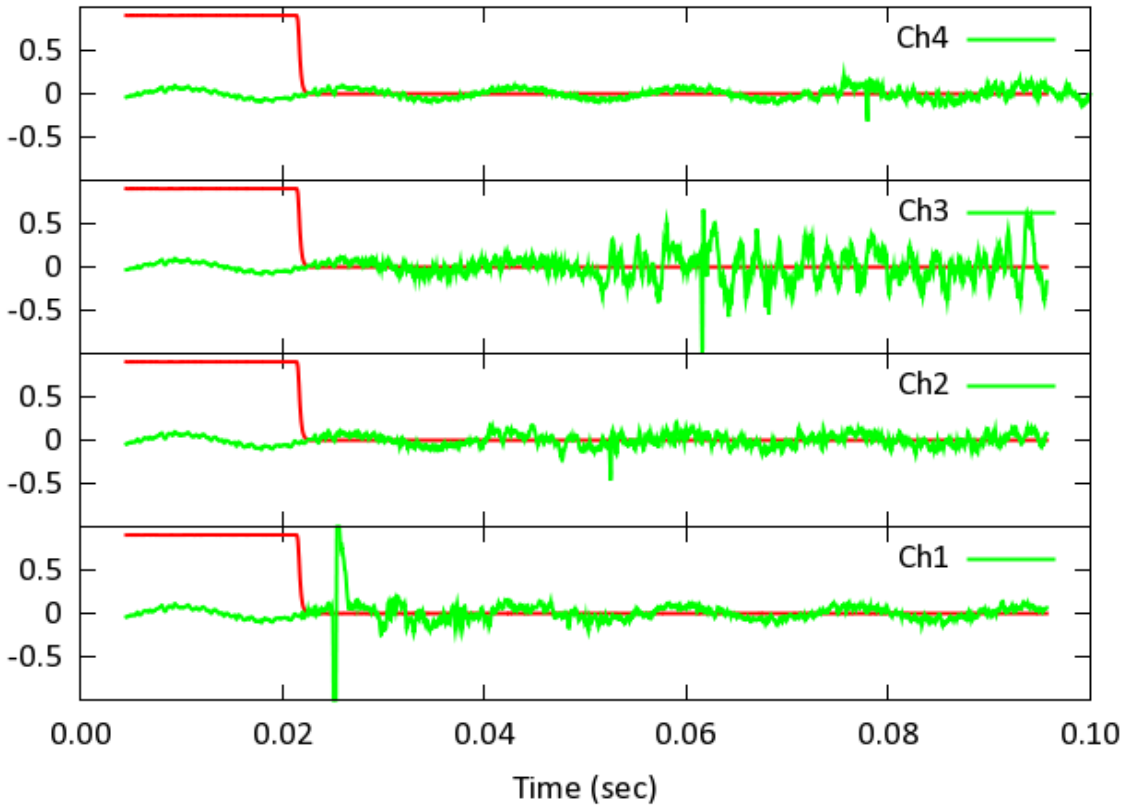


Some FE processing occurred while performing scans of SS sensors while quenching at T < 2K

Quench at 34.4 MV/m, Q_0 at quench = 1.2 x 10^{10}
FE onset at 22 MV/m, radiation levels moderate (~6mR/hr).
In π-mode the SS sensors indicate quench at cell #1.

Cavity Performance : TB9ACC014

In the π-mode, the quench location is in cell #1, nearest the FPC (not the "dented" cell!)



(D. Sergatskov)

Response of OST's when cavity was quenching at 34MV/m in the π-mode. Channel 1 is located nearest cell #1, channel 4 is nearest cell #9. Channels 2 and 3 are located approximately equidistant between channels 1 and 4.

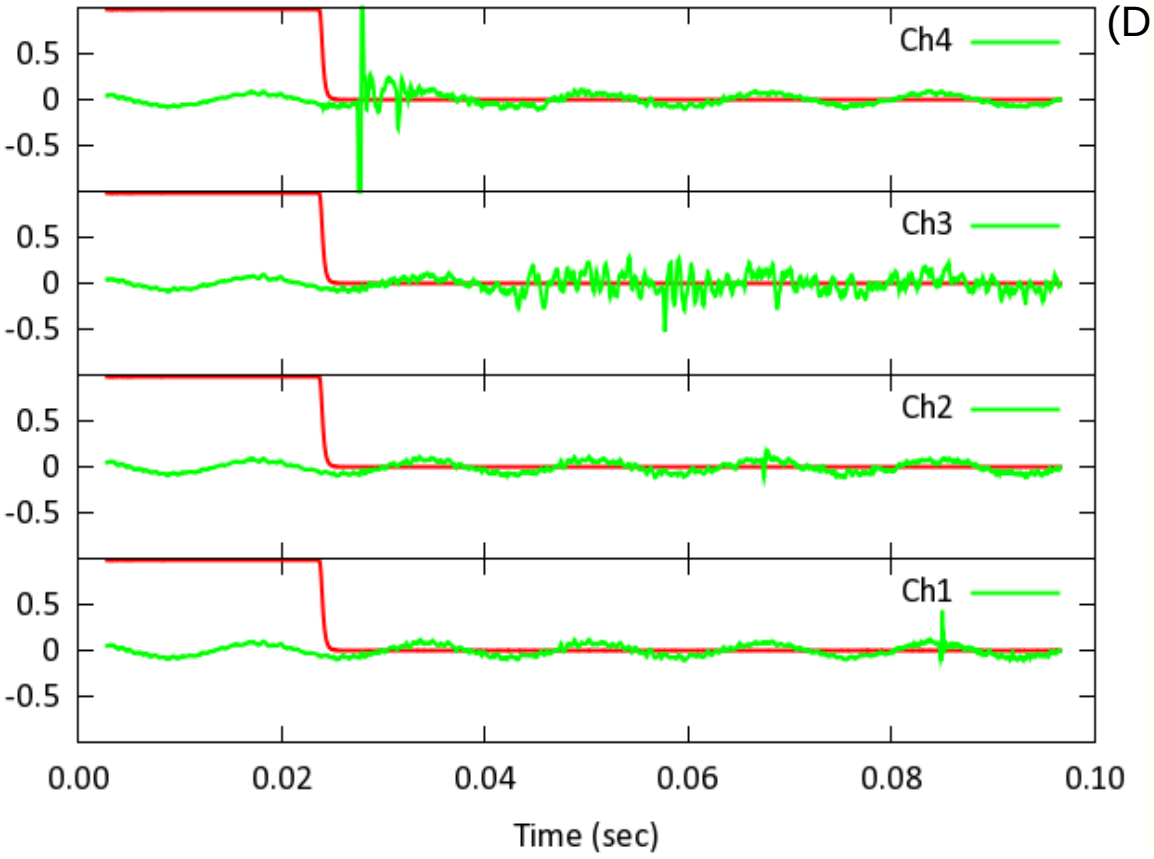
Cavity Performance : TB9ACC014

Fermilab

(D. Sergatskov)

Quench location shifts when in 8π/9 mode – now it is cell #9 (the "dented" cell)

In this mode, cells 1 & 9 see ~ equal fields, in π-mode, cell 1 detuned by ~20%.



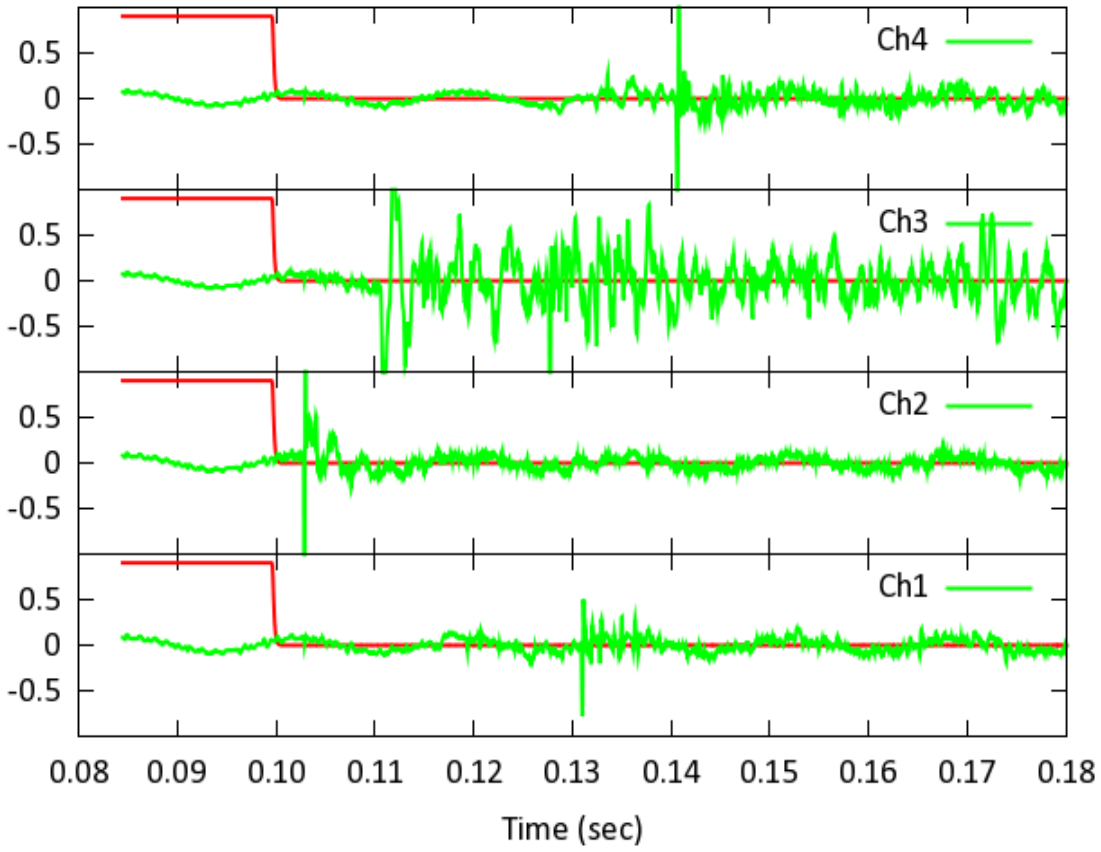
Response of OST's when cavity was quenching at 34MV/m in the 8π/9 mode. Channel 1 is located nearest cell #1, channel 4 is nearest cell #9.

Cavity Performance : TB9ACC014

(D. Sergatskov)

Quench location in the π/9 mode is between cells #4 and #5 – closer to cell #4.

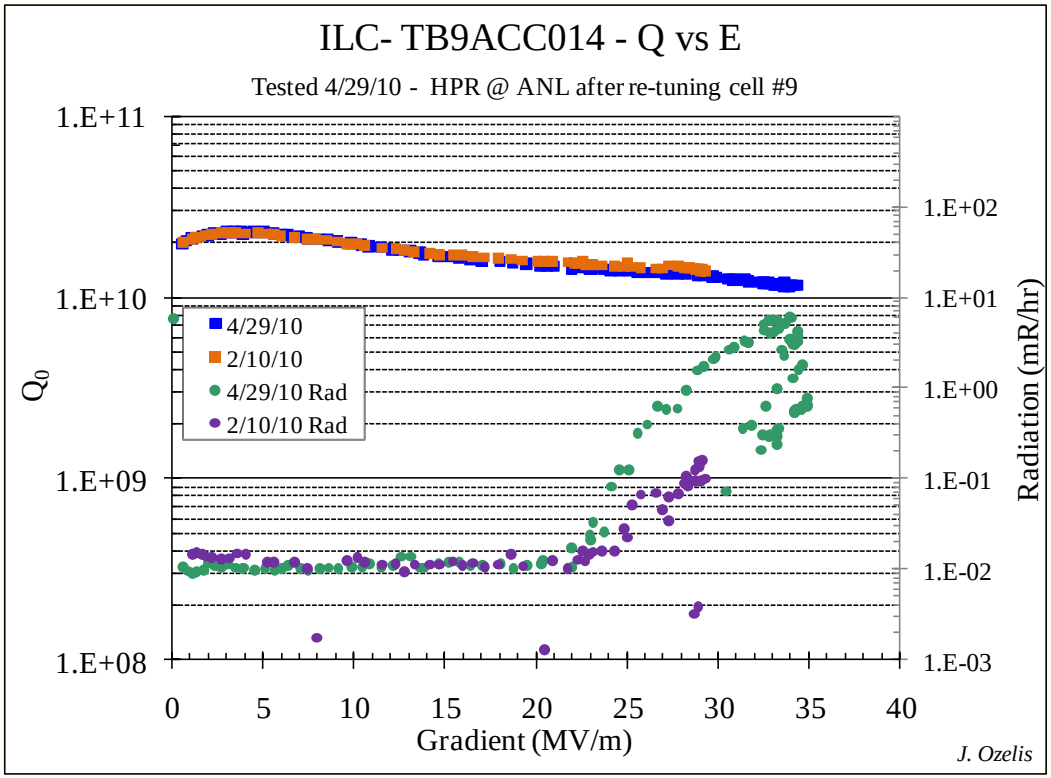
In this mode, the fields in cells 4 & 5 are essentially equal.



Response of OST's when cavity was quenching in the π/9 mode at ~45MV/m. The quench signals arrive at channels 2 and 3 first, and significantly earlier in channel 2, indicating that the quench location is not cell #5 but cell #4. Cavity performance is limited by both end cells (~34MV/m).

Cavity Performance : TB9ACC014

How does this test compare to previous test?



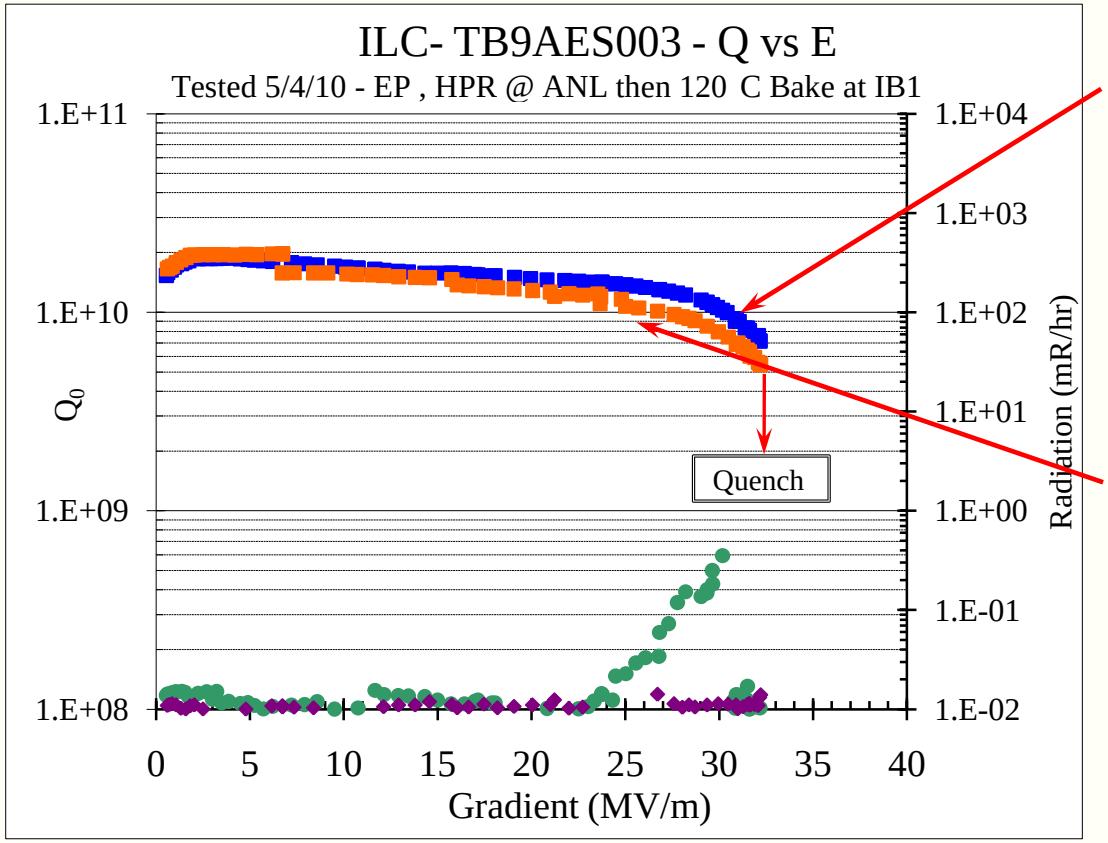
Q_0 vs E curves are nearly identical (low field Q_0 "hump" and Q-slope) - would not be expected if there were a calibration error (P_{loss} would be wrong).

Cavity showed a 20% improvement in maximum gradient during this latest test.
Field probe calibration differed by ~8% → ~4% change (increase) in gradient.
Improvement in gradient to 34.4MV/m from 29MV/m is real - result of cumulative FE processing during the two test cycles ?
Initial FE during this test was actually higher than the initial FE during the last test!

Cavity History : TB9AES003

- Cavity tested 1/12/20 after HPR/assy at ANL (after grinding and EP (50μm) @ KEK)
- Reached 30 MV/m (FE and RF limit)
- Additional HPR, then retested 1/26/10
- Reached 34.5 MV/m (quench limited)
- Optical inspection,“horseshoe” stain observed (iris, cell #1 and BP), polished away w/ AlO_2 paper
- Cavity re-tuned (FF 87% → >98%)
- Additional light EP (20μm), then HPR/Assy @ ANL
- 120°C bake at IB1
- Vertical test 5/4/2010

Cavity Performance : TB9AES003



During initial power rise, note error in P_{ref} measurement. Suspect cable/connector heating (later verified – vent holes in connector improperly drilled).

Periodic re-cal of cable when lowering power fixes this.

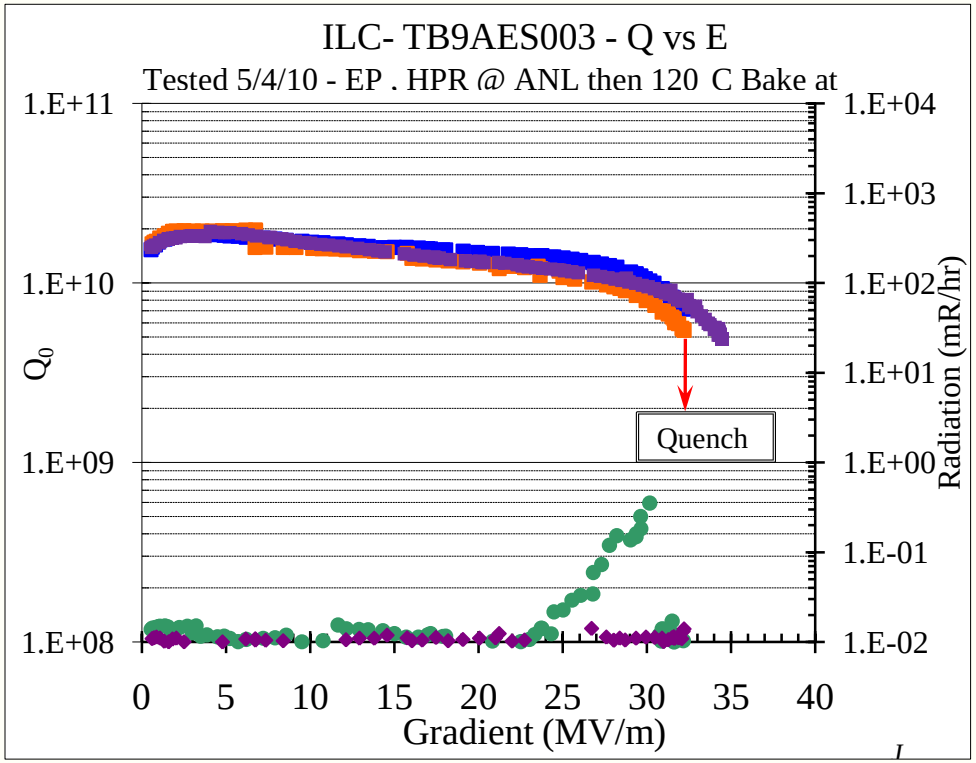
No error on E (P_{tran} used only). Q_0 error up to 25% if not corrected.

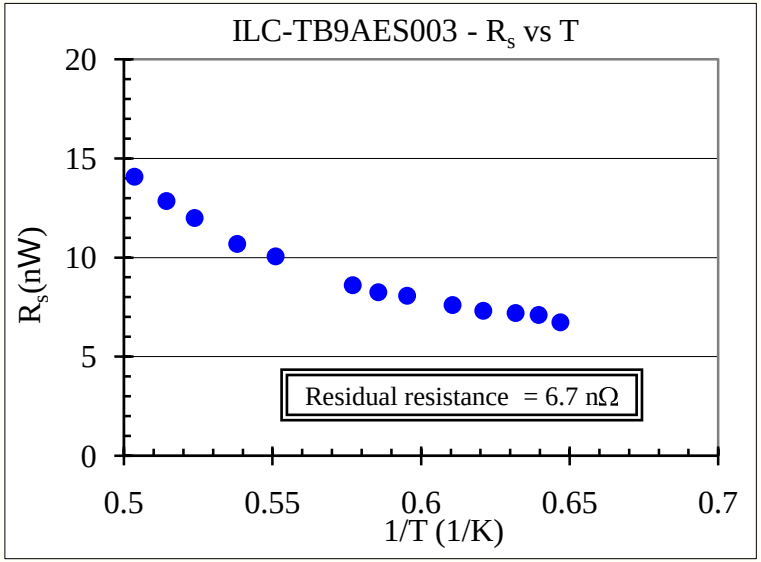
Low field $Q_0 = 1.9 \times 10^{10}$, quench at 32.2 MV/m, Q_0 at quench = 5.6×10^9 . FE onset at 23 MV/m, radiation increasing, then processed away. Still see Q-drop at ~27-28 MV/m even w/o FE loading, with 120°C bake. Mode measurements suggest cells 4/6 lowest performers.

Cavity Performance : TB9AES003

Comparison w/ earlier tests – see ~7% decrease in maximum field (within meas error and retuning effects).

Additional EP of this cavity has not yielded any improvement.





Residual surface resistance = 6.7nΩ; last time was 6.0nΩ .

Essentially no change/improvement, consistent with other good cavities.

Summary

Cavity TB9RI024 is quench limited to 29MV/m, limiting cell identified as cell #2 using second-sound technique. No obvious feature observed in quenching cell (cell #2). Cavity was processed again (light EP) and is undergoing HPR & assy, in preparation for 120°C bakeout and vertical test.

Cavity TB9RI026 is field emission limited to 19.6 MV/m, after initially reaching 29 MV/m. The source of the FE *may* be in the ends. A feature on the iris between cells 8 & 9 was observed during the latest pre-vertical test optical inspection. Additional optical inspection will be performed next, followed probably by additional light EP (and perhaps optical inspection to document the evolution of this feature after additional EP), then 120°C bakeout and re-test (w/ thermometry and OST's).

Summary

Cavity TB9ACC014 is quench limited to 34MV/m (up from 29MV/m) and still has some FE. Limiting cells are cell #1 in π-mode & cell #9 in $8\pi/9$ mode (essentially same gradients), verified using second-sound technique (and also thermometry on cell #9).

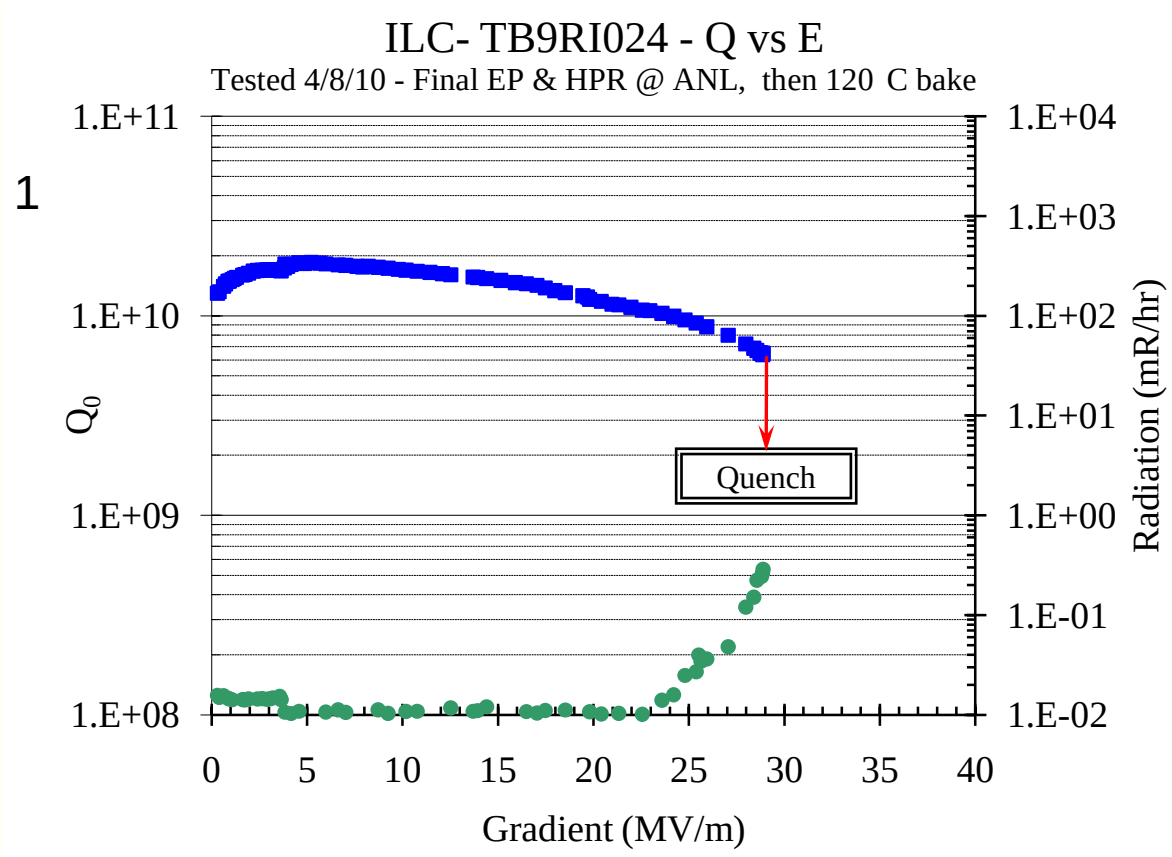
Cavity TB9AES003 is quench limited to 32.2 MV/m, with little/no FE present. Limiting cells are cells 4/6 – note that cell 4 was site of original 20MV/m quench limit. Additional EP did not improve performance. Noticeable high-field Q-drop even with 120°C baking and absence of FE loading – correlated with surface roughness?

Cavity History : TB9RI029

- Fabricated by RI
- Bulk (140μm) EP at RI
- Inspections (visual, CMM, RF, optical)
- H de-gassing (800°C, 2 hours) @ JLab
- Tuning
- Optical inspection
- Light EP (22μm), HPR (2x), assy
- 120°C bakeout (48hrs)
- Vertical test

Cavity Performance : TB9RI029

Low field Q_0 = 1 10^{10}



Quench at MV/m, Q_0 at quench =
FE onset at MV/m, radiation levels moderate. Fairly strong Q-slope beginning at ~ MV/m, even without presence of FE.