A Cross-Lab Qualification of Modified 120°C Baked Cavities

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Motivation

Within a cross-laboratory effort to understand and standardize the nitrogen-infusion [1] and the low T bake [2] procedure, one large grain and two fine grain single-cell cavities were treated and tested at FNAL.

Subsequently they were sent to JLab and/or DESY for a cross-laboratory comparison of the RF performance and its dependence on test conditions like cooldown and the magnetic environment of the cryostats.

Cavity History

1DE3 (FG|Heraeus|RRR300)

- Test 1 at DESY
- Sent to FNAL for Infusion
- 1st N-Infusion @ 120°C failed due to air leak
- Reset with 60 µm EP (FNAL)
- 'Accidentally' low T baked (75°C/4h before 120°C/44h)
- 2nd N-Infusion @ 120°C at FNAL
- Test 2 at FNAL
- Sent to DESY
- HPR + Test 3 at DESY
- HPR + Test 4 at DESY

1DE20 (LG|Heraeus|RRR505)

- Cavity sent to FNAL 2011
- Tumbling / Coating studies (FNAL)
- Reset with 60 µm EP (FNAL)
- Low T baked (FNAL)
- N-Infusion @ 120°C at FNAL
- Test 1 at FNAL
- Sent to DESY
- HPR
- Test 2-4 at DESY

AES022 (FG|Tokyo Denkai)

- LCLS-II recipe qualification
- Reset with EP (FNAL)
- Low T bake (FNAL)
- Test 1 at FNAL – 'bifurcation' seen
- Sent to Jlab – Test 2 – 'bifurcation' seen
- Sent to FNAL – Test 3
- Sent to DESY – Test 4
- Sent to KEK – currently tested

1DE3

- After arrival at DESY, in test 3, the cavity showed a strong FE event during first power rise. The values of the quality factor at low accelerating fields were comparable to FNAL.

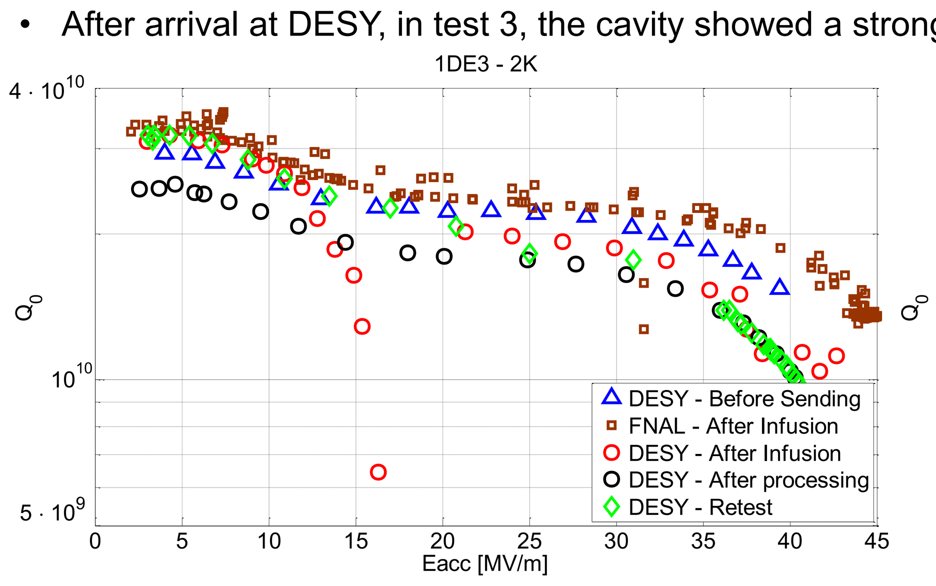


Fig. 1: Q vs. E at 2K for different steps. At low fields below ~15 MV/m, the cavity performance is identical (within errors) between the labs. After infusion an increased Q_0 is observed. After the FE event the high Q_0 cannot be recovered.

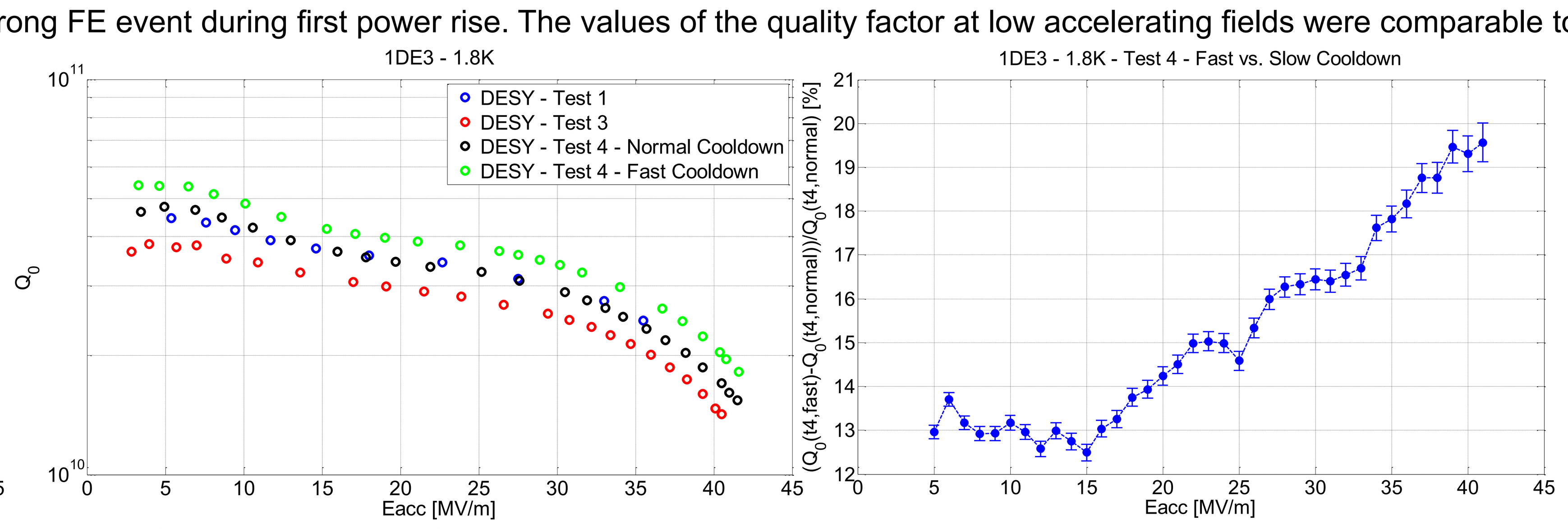
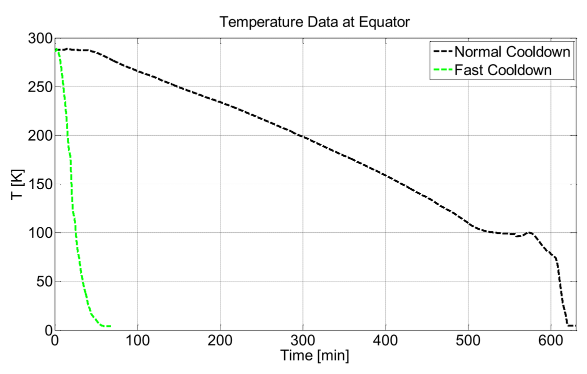


Fig. 2: Q vs. E at 1.8K of 1DE3 (left hand plot). The performance before infusion (Test 1 - blue) and after additional HPR after the FE event (Test 4 - black) is identical. Field emissions, seen in the test after the infusion (Test 3 - red), are causing lower Q_0. The subsequent fast cooldown (Test 4 - green) shows a significantly higher quality factor compared to the normal cooldown (Test 4 - black) of the retest. The right hand plot shows the normalized ΔQ_0 (fast minus normal cooldown). A significant difference of more than 10% is seen.



Tab. 1: Cooldown Parameters for 1DE3

	Normal	Fast
T_{start}	288 K	288 K
$dT/dt\|T_c$	6.4 K/min	1.8 K/min
$dT/dt\|^{288K}_{100K}$	0.5 K/min	13.4 K/min
$dT/dx\|^{Eq}_{Bottom@Tc}$	8.7 K	7.5 K

1DE20

- The DESY vertical test results vary and differ from FNAL measurements. Differences are not yet understood.

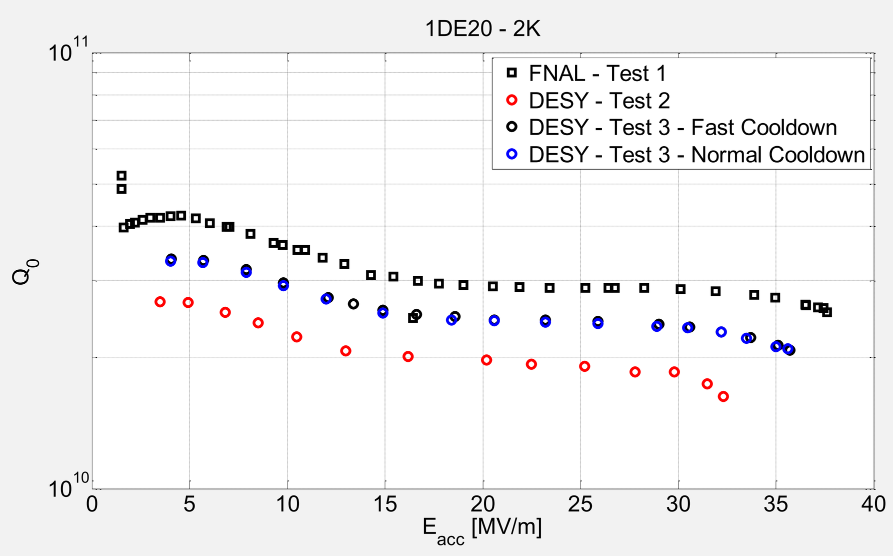


Fig. 3: For the the test after infusion (Test 2 - red) the cavity was equipped with coils for RRR measurements. Retesting (Test 3 - black and blue) showed higher Q_0. This difference as well as the difference to the original FNAL test is not understood.

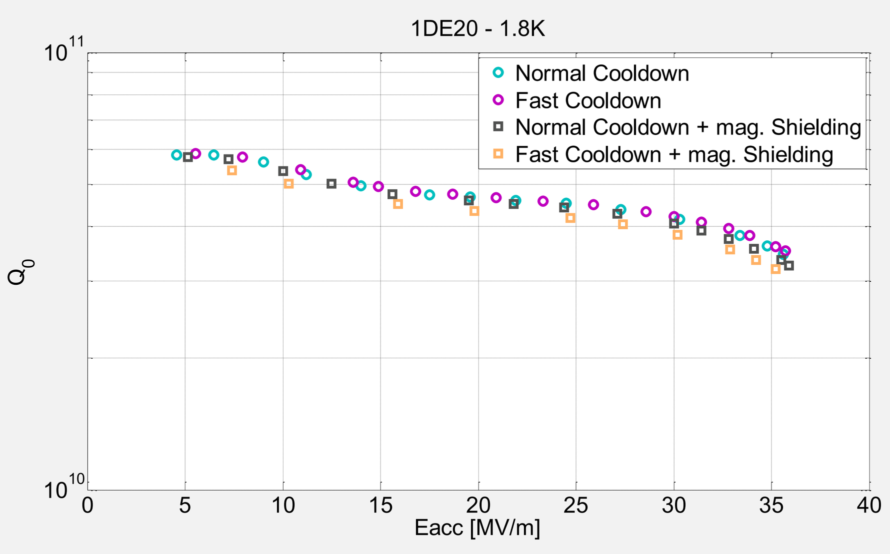


Fig. 4: Q vs. E tests at 1.8K for 1DE20. Test 3, shown in the left hand plot, was repeated with additional magnetic shielding. This additional Test 4 was performed after normal and fast cooldown. All Q_0(E) curves are almost identical.

Different Quality Factor

- Test 2: $Q_0(2K) = 2.7 \cdot 10^{10}$ (10 nΩ); $Q_0(1.8K) = 4.5 \cdot 10^{10}$ (6 nΩ); R_{res} = 3 nΩ
  Test 3: $Q_0(2K) = 3.4 \cdot 10^{10}$ (8 nΩ); $Q_0(1.8K) = 5.9 \cdot 10^{10}$ (4.6 nΩ); R_{res} = 2.1 nΩ
  → **ΔQ(2K): +26% ; ΔQ(1.8K): +31%,** ΔR_{res} not sufficient for this change
  - No influence of cooldown, cryostat and insert
  - ΔR_{res} origin: most likely current of RRR coils; created flux being trapped at T_c

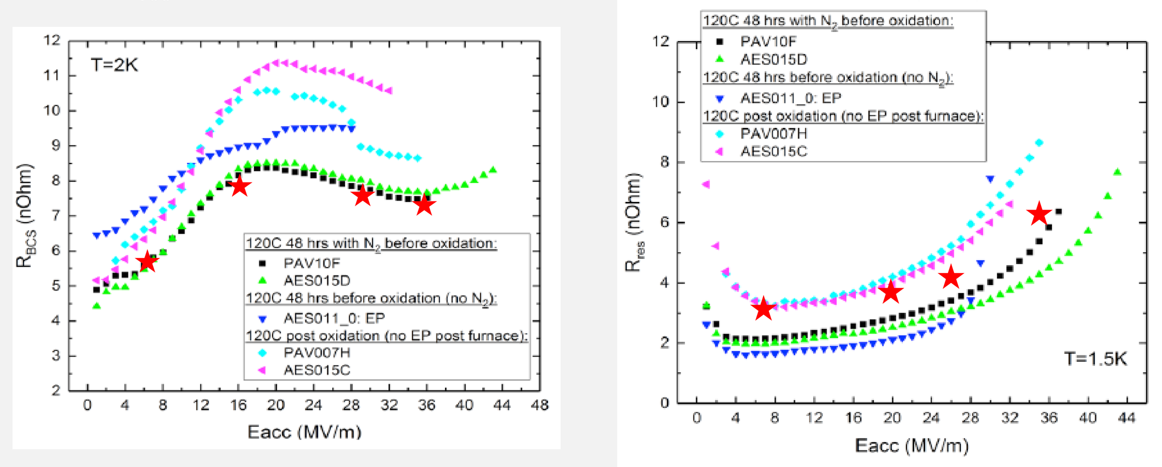


Fig. 5: Deconvolution into R_{BCS} and R_{res} of typical nitrogen infused cavities at Fermilab. - Plot taken from [1]. DESY measurement (red stars) at 1.6K. R_{BCS} 'behaves' infused but higher R_{res} observed.

AES022

- Cavity tested at FNAL, JLab [3] and DESY. Cavity tested at DESY as received – no vacuum connections done.

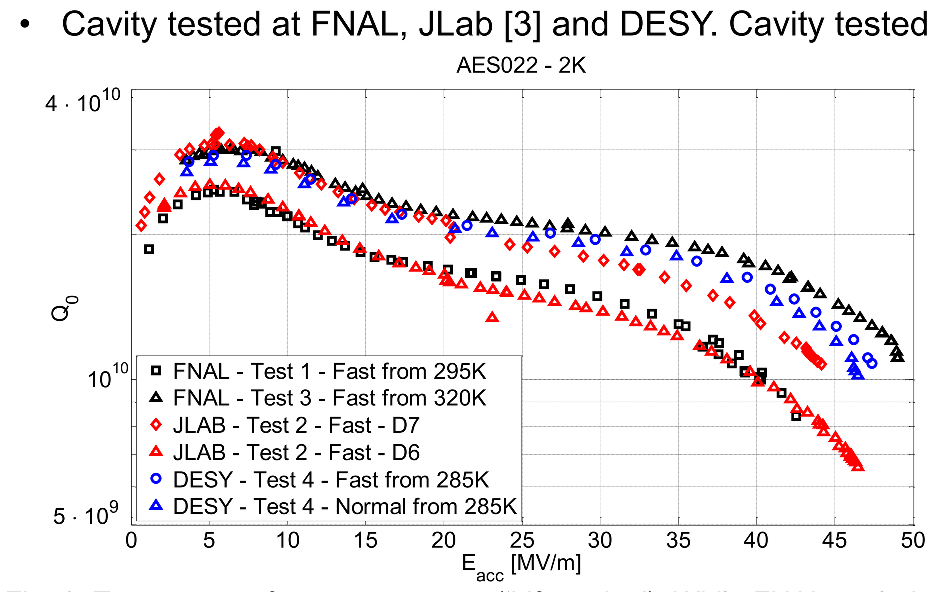


Fig. 6: Two groups of curves are seen ('bifurcation'). While FNAL cooled down with different starting temperature, JLAB used two different test cryostats (D6 / D7). In both cases the Q_0(E) shifted. DESY applied the standard and the fast cooldown; results are identical. The upper branch of the Q_0(E) curves includes results form all three labs.

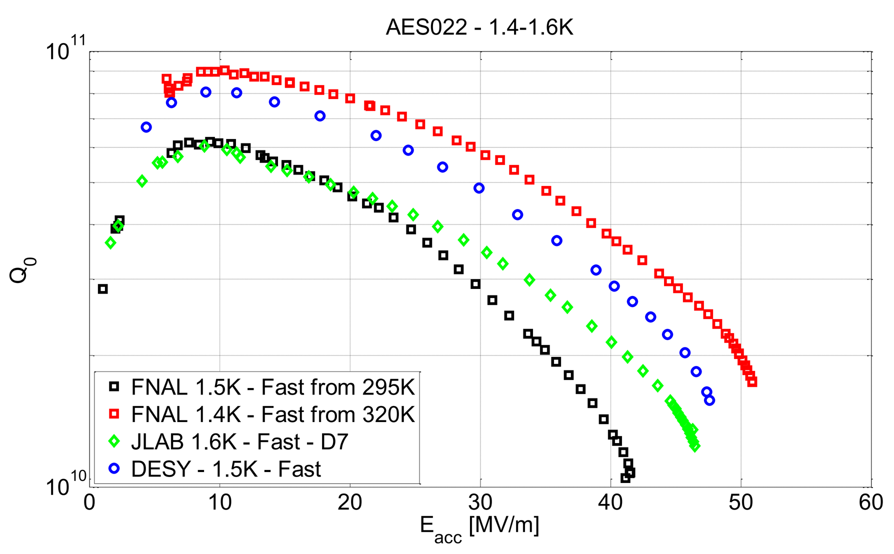


Fig. 7: Q vs. E curves at different low temperatures across the labs.

Multipacting

- JLab [3] & DESY observed Multipacting during AES022 tests
  - DESY observed Multipacting only in second power rise after a quench in the first power rise and not in all cooldowns.
  - JLab pumped the cavity during testing, possibly allowing a small amount of water to reenter the cavity through cryo-pumping activating MP.
- During MP quench, 6-8 mG were trapped
  - Q_0 went down from 2.8 to 2.6 x 10^{10}
  - Sensitivity can be calculated to ≈ 0.1 nΩ / mG

Origin of Branching

- FNAL observes a dependency on the cryostat temperature before the cooldown. Once the upper branch is measured, the lower cannot be reproduced [4].
- JLab observes both branches, but gives a different hypothesis for explanation based on additional losses caused by different magnetic environments in two different cryostats [3].
- DESY only measures the upper branch and does not observe any dependency on cooldown parameters. No other cryostat was used.

Conclusions

All measurements across the labs are in agreement with each other – observed differences originate from individual effects

- **1DE3**
  - Q_0 measurements of FNAL and DESY at low fields are in agreement. Strong FE event in DESY Test 3 prevents further comparison.
- **1DE20**
  - R_{BCS} at DESY is in agreement with cavity results from FNAL on infused cavities. Unidentified contributions to R_{res} exists, compared to FNAL.
- **AES022**
  - Measurement across laboratories of upper branch are well within agreement taking MP into account. Lower branch couldn't be reproduced at DESY and the origin of branching is not unambiguously identified.
  - Influence of cooldown parameters was not observed at DESY – only the upper branch was measured.

References

[1] Grassellino et al., Supercond. Sci. Tech 30.9 (2017): 094004.
[2] Grassellino et al., arXiv preprint 1806.09824 (2018)
[3] Palczewski, A., High Q_0/High gradient at JLab: LCLS-2 HE 3N6 doping, furnace issues and FNAL 75°C retests, TTC Workshop 2019, Vancouver
[4] Bafia, D. et al., Low T Bake – Cool Down Studies, TTC Workshop 2019, Vancouver