R & D on $\beta = 0.81$ Cavities: Status Report

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Motivation

- Efficient acceleration between $\beta \approx 0.7$ and $\beta \approx 0.9$ (other proposed solutions will have significantly lower efficiency and higher cost) (if ILC does not provide 300 cavities for free).
- Benefit from experience with $\beta < 1$ acceleration at SNS: minimise technical risk.
- Cell shape compatible with rigorous surface preparation.
- Maximum overlap with ILC.

Maximising Overlap with ILC

- Same frequency (1.3 GHz) and operating temperature.
- Same beam tube diameter as TeSLA Test Facility cavity.
- Same helium tank as TTF/ILC except shorter length.
- Same input coupler (antenna length adjusted if needed) and HOM couplers (if needed) as TTF/ILC.
- Same tuner as TTF/ILC.
- Same cryomodule as TTF/ILC except possibly different length.
- Same RF system as TTF/ILC.
- Same steps for cavity fabrication (deep drawing, electron beam welding).
- Same steps and equipment for etching, rinsing, assembly.
- Same requirements for surface quality and cleanliness.

Development Effort

- 7-cell superconducting cavity has been designed for $\beta = 0.81$.
- Cell shape is similar to the SNS $\beta = 0.81$ cavity adjustment for ILC compatibility: $f = 1.3$ GHz instead of $f = 805$ MHz, same beam tube as TTF.
- Also of interest: explore potential of large grain Nb for improved performance and/or cost reduction.
- Four single-cell prototype cavities have been fabricated and tested: 2 fine grain, 2 large grain.
- Two 7-cell cavities have been fabricated (not yet tested).

Participants

Fermilab: Funding for project and initial design work.

MSU: Final design, cavity fabrication, surface preparation, RF testing.

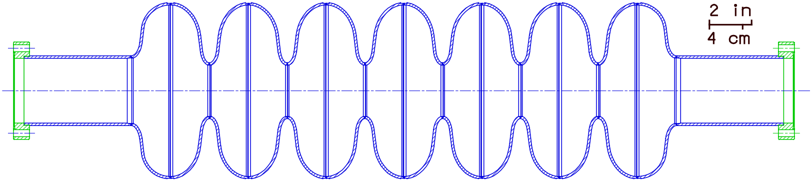
Jefferson Lab: Provided large grain Nb; vacuum furnace treatments, surface preparation, RF testing.

Cavity Design

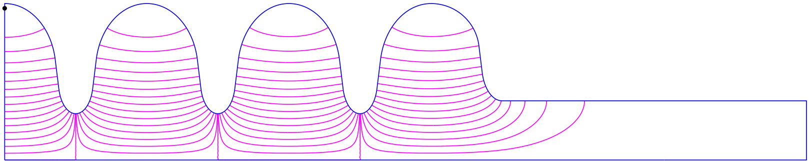
Selected cavity parameters and comparison with SNS cavity

Cavity	SNS 6-cell	FNAL 7-cell
β_g	0.81	0.81
wall inclination	7°	7°
E_p/E_a	2.19	2.19
cB_p/E_a	1.44	1.41
cell-to-cell coupling	1.5%	1.6%
R/Q per cell	80.8 Ω	79.1 Ω
Geometry factor	233 Ω	227 Ω

Values for FNAL cavity were calculated with SUPERFISH

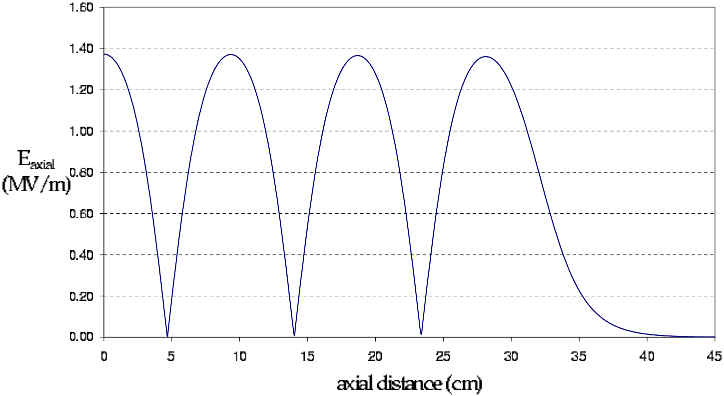


7-Cell $\beta_g = 0.81$ Cavity

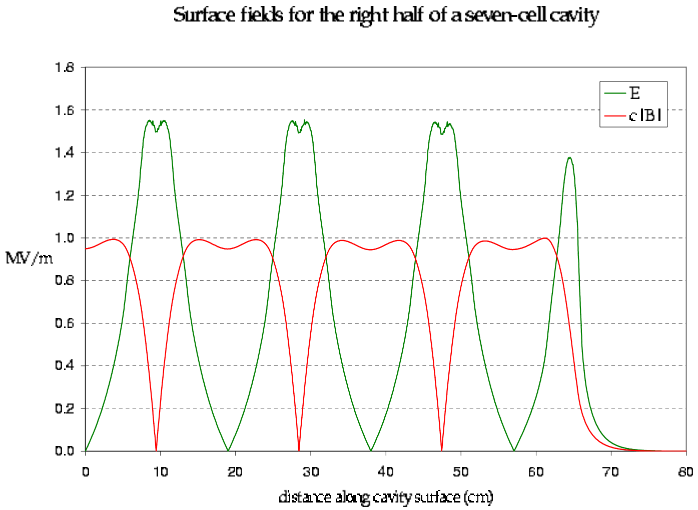


Electric field lines from SUPERFISH

FIELD FLATNESS ~ 0.9 %



Electric field on axis (SUPERFISH)



Surface fields (SUPERFISH)

Cavity Fabrication and Preparation

- Sheet Nb of thickness 2.8 mm was used.
- Forming done at MSU and in local area; electron beam welding by industry.
- Nb-Ti flanges with knife edges were electron-beam welded to the beam tubes.

Fine Grain Cavities

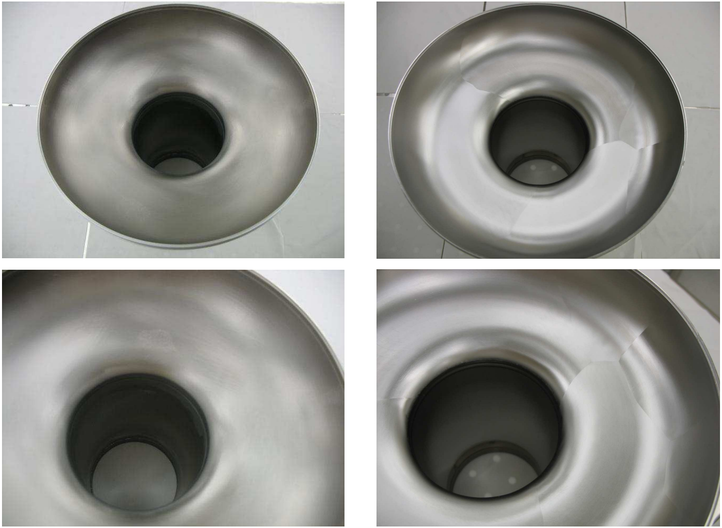
- Nb sheet of RRR $\geq$ 260 was rolled.
- Cu gasket knife edge seal.
- Not fired for H degassing.
- c. 180 μm etch (BCP); 30 to 50 μm for repeat etching.
- High-pressure rinse with ultra-pure water for 45 to 120 minutes.
- RF testing, then Ti treatment at 1250°C, etch, HPWR, and RF test again.

Large Grain Cavities

- Nb sheet was cut via wire EDM from an ingot with RRR $\sim$ 280 and Ta content $\sim$ 800 ppm.
- After iris weld, half-cells were mechanically polished to smooth off grain boundaries.
- Knife edges were machined off and In seals were used.
- Fired in vacuum at 600°C for 10 hours for H degassing.
- 50 μm etch (BCP) before firing, another 50 μm after firing.
- High-pressure rinse with ultra-pure water for 60 minutes (HPWR).

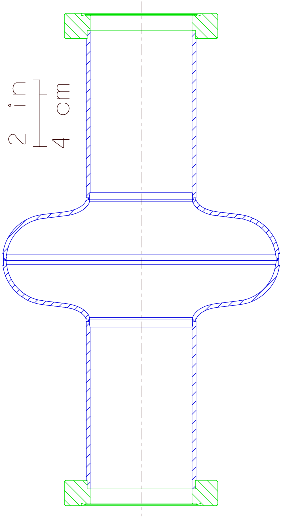
RF Test	Preparation
# 1	see above, no additional heat treatment
# 2	vacuum bake-out for 12 hours at 120°C
# 3	3 hour Ti treatment at 1250°C, 50 μm etch, HPWR
# 4	vacuum bake-out for 12 hours at 120°C

Dies for deep drawing of half-cells



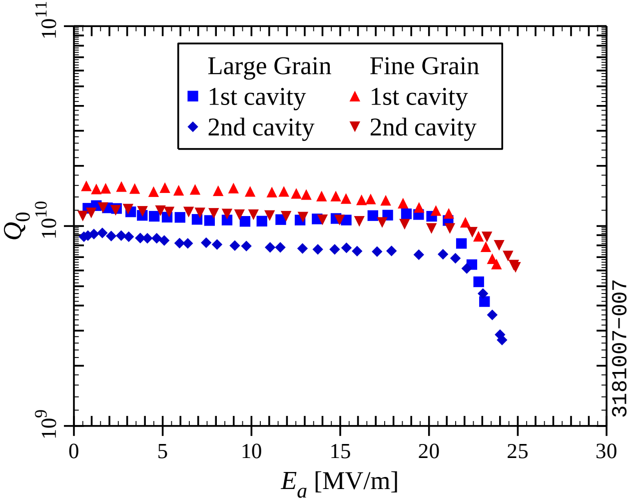
Fine grain (left) and large grain (right) half-cells

Etching and rinsing of fine grain cavity

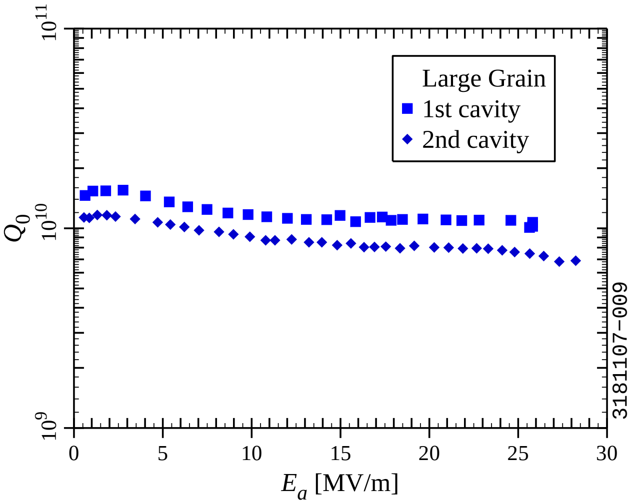


Drawing of single-cell $\beta_g = 0.81$ cavity and photograph of fine grain cavity on insert

RF Tests: Single-Cell Cavities



RF results at 2 K for fine grain and large grain single-cell cavities after Ti treatment: limit = quench



RF results at 2 K for large grain single cell cavities after Ti treatment and bake-out: limit = quench

Fabrication of 7-cell cavities

Electron beam welding of 7-cell cavities

Completed fine grain (top) and large grain (bottom) 7-cell cavities

Close-up view of large grain 7-cell cavity

Conclusion

- Reasonable RF performance was reached in all 4 single-cell prototype cavities. The performance is adequate for use in a proton linac.
- Higher gradients were reached in the large grain cavities before Ti treatment (however, the large grain cavities were fired at 600°C and the fine grain cavities were not).
- Results after Ti treatment were similar for fine grain and large grain cavities.
- Two 7-cell cavities have been fabricated, one from fine grain Nb and the other from large grain Nb. They have not yet been tested.

Possible Future Work

- Field flatness tuning of 7-cell cavities.
- RF testing of 7-cell cavities.
- Post-purification and retesting of 7-cell cavities.
- Would require modest investment of additional funds.

Appendix

Selected cavity parameters and comparison with SNS and TTF cavities

Cavity	TTF 9-cell	SNS 6-cell	FNAL 7-cell	FNAL 1-cell
β_g	1	0.81	0.81	0.81
wall inclination	13.3°	7°	7°	7°
E_p/E_a	2.0	2.19	2.19	2.18
cB_p/E_a	1.28	1.44	1.41	1.58
cell-to-cell coupling	1.8%	1.5%	1.6%	-
R/Q per cell	115 Ω	80.8 Ω	79.1 Ω	62.3 Ω
Geometry factor	270 Ω	233 Ω	227 Ω	229 Ω

Values for FNAL cavity were calculated with SUPERFISH

RF Tests: Fine Grain

Before Ti treatment

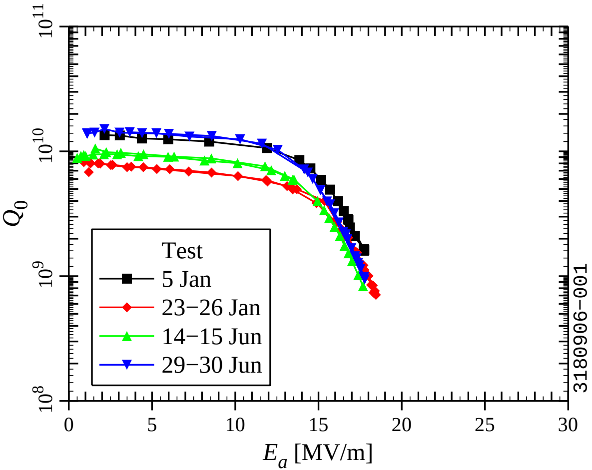
- Several tests with similar results.
- Both cavities limited by hard barrier ("quench").
- Vacuum bake-out improved BCS Q of 2nd cavity but did not help the high-field performance.
- Highest field reached: $E_a = 18$ MV/m ($E_p = 40$ MV/m, $B_p = 96$ mT).

After Ti treatment

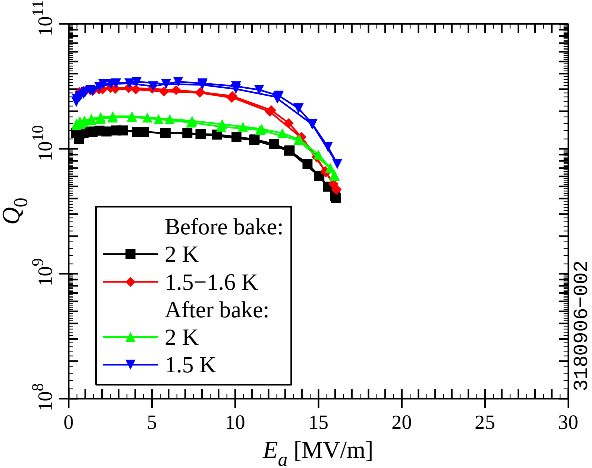
- High field Q-drop (did not try baking).
- Cavities were ultimately limited by quenches.
- Highest field reached: $E_a = 25$ MV/m ($E_p = 54$ MV/m, $B_p = 131$ mT).

RF Tests: Large Grain

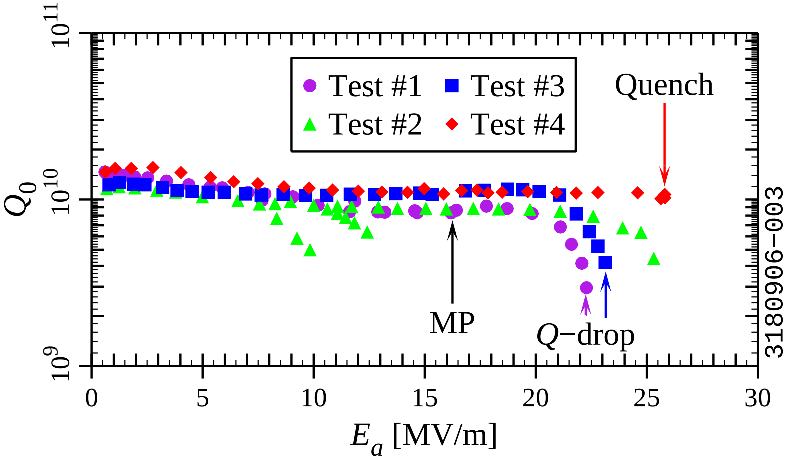
- High field Q-drop, eliminated by bake-out.
- Cavities were ultimately limited by quenches.
- Highest field reached: $E_a = 28$ MV/m ($E_p = 62$ MV/m, $B_p = 148$ mT).



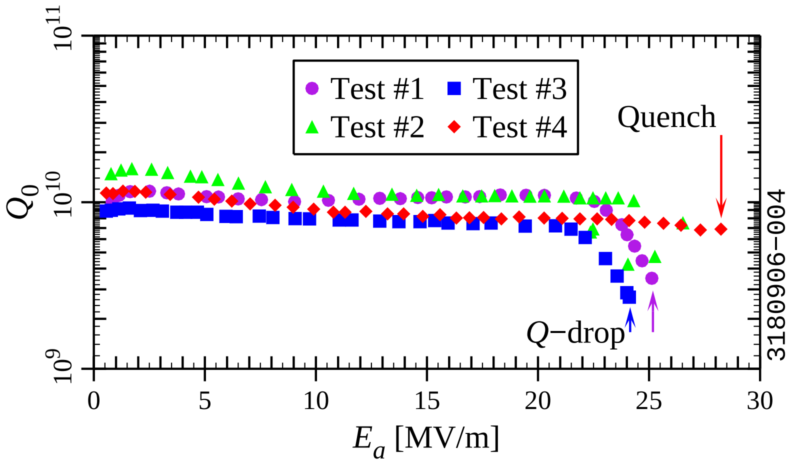
First fine grain cavity results at 2 K before Ti treatment



Second fine grain cavity results at 2 K before Ti treatment



First large grain cavity results at 2 K before/after Ti



Second large grain cavity results at 2 K before/after Ti