TTC2012

Design, fabrication, and high Q_0 testing of the main linac cavity for the Cornell ERL

Cornell University

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TTC Meeting

2012 November 7

ERL Cavity Overview

ERL@CESR, Cornell

- 5 GeV, 100 mA CW beam
  - 8 pm emittance, 2 ps bunch length
- Stable operation
  - Strong HOMs can cause beam breakup
  - ~200 W HOM power in beamline loads/cavity
- CW operation
  - Q(1.8 K) = 2×10^{10} @ 16.2 MV/m
    - 10 W cryogenic loss from fundamental/cavity
    - ~4 MW wall power

Cornell Energy Recovery Linac Project Design Report
Editors: G. Hoffstaetter, S. Gruner, M. Tigner

Outline

- Cavity Design
  - Central focus: Maximize threshold current through linac
    - Center cell geometry
    - End cell geometry
    - Beam line HOM absorbers
    - Fundamental power coupler design
  - Simulate ERL performance with realistically shaped cavities
- Fabrication & Test Results
  - Prototype cavity fabrication process
  - Installation into horizontal test cryomodule
  - Horizontal Cryomodule Test Results (HTC-1 and HTC-2)
- Conclusions & Future Plans

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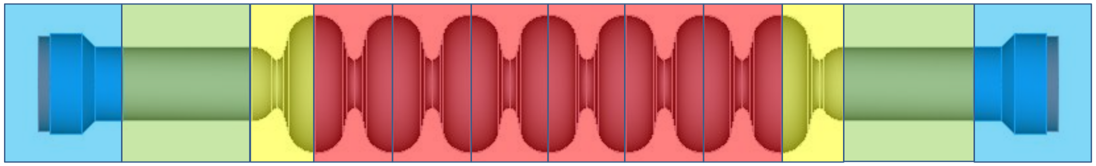
Cavity Design



Goal: Maximize I_{th} > 100 mA
(under constraints)

Center cells

- Geometries are (nominally) identical
- Responsible for general properties of HOM spectrum
  - Controls frequencies of HOM passbands and dispersion relations
  - Determines cell-to-cell coupling and how sensitive HOM spectrum is to variation in cell shape

End cells

- Asymmetric design helps prevent trapped modes
- Responsible for coupling HOMs to HOM absorber
  - Directly controls quality factors of HOMs

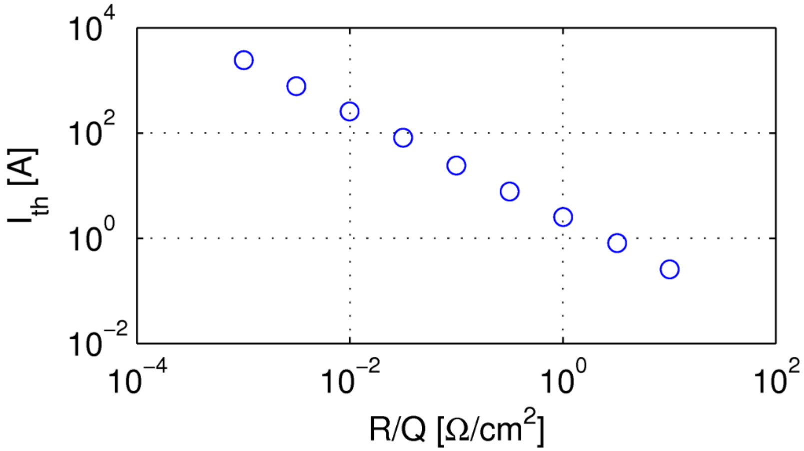
Beam Pipe

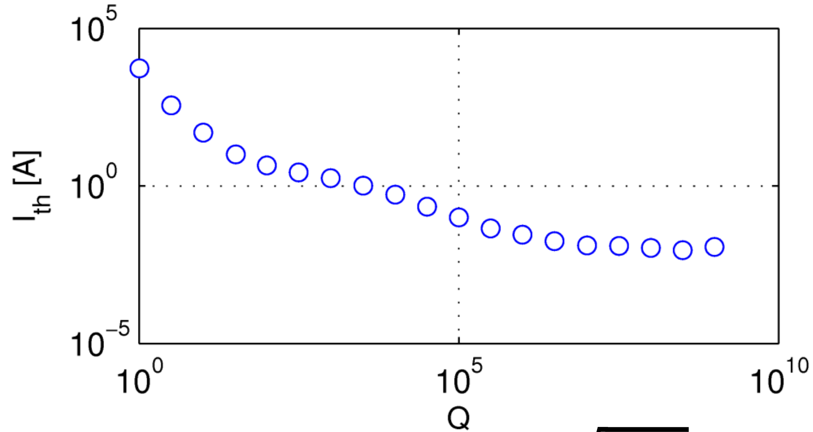
- Should be short to improve linac fill factor but long enough to avoid dissipating too much power from the fundamental mode in HOM loads

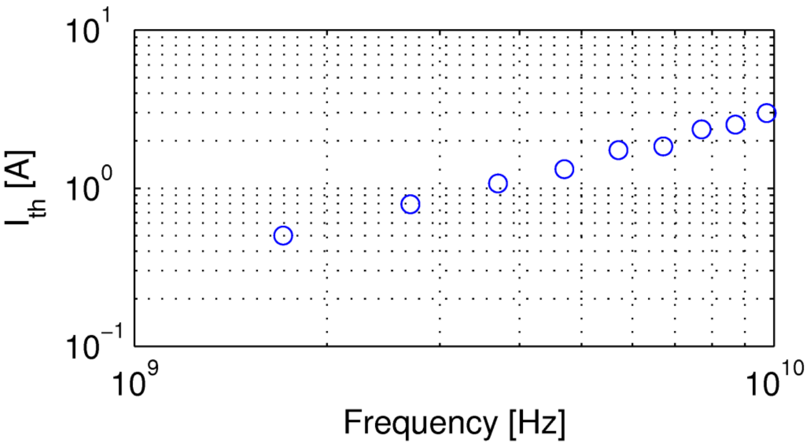
HOM load

- Absorber material properties determine specific mode losses.
- Also serves as bellows connecting cavities

Scaling of threshold current





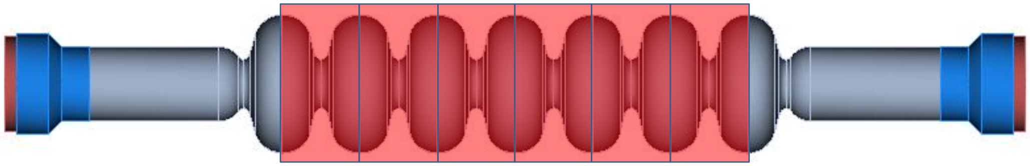


$$\xi_\lambda = \left(\frac{R}{Q}\right)_\lambda \frac{\sqrt{Q_\lambda}}{f_\lambda}$$

$$I_{Th} \propto \max(\xi_\lambda)^{-1}$$

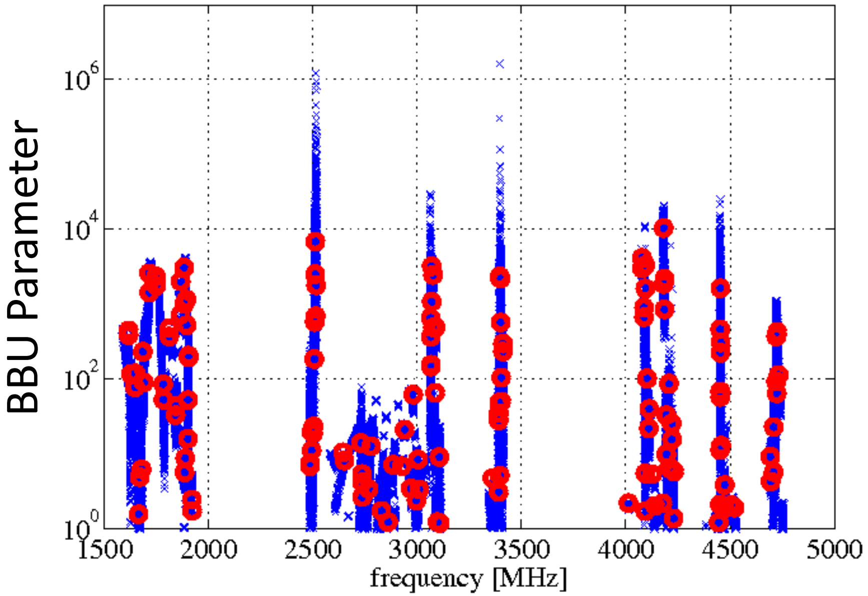
Cavity Design for Cornell's Energy Recovery Linac
N. Valles, M. Liepe; Proceedings of the 2010 Linear Accelerator Conference, Tsukuba, Japan (2010).

Center Cell design

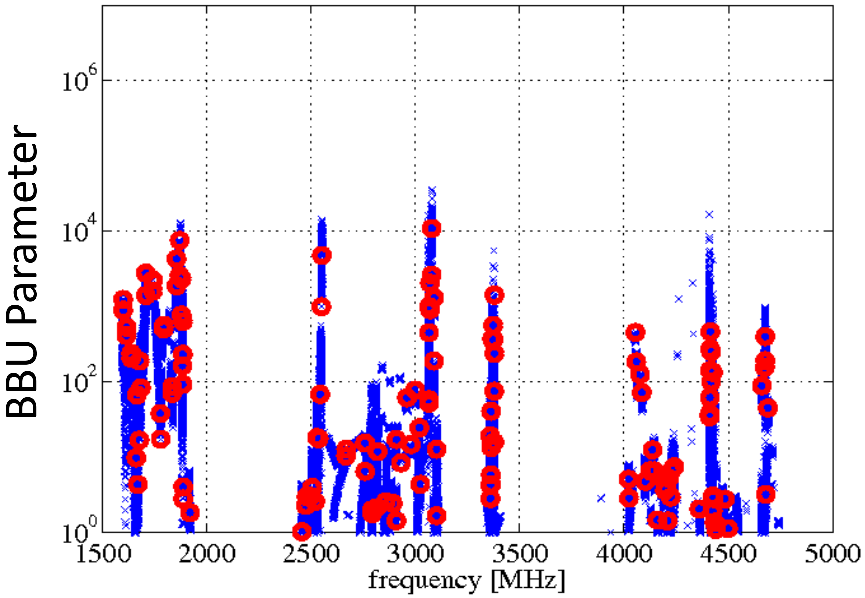


Seven-Cell Cavity Optimization for Cornell's Energy Recovery Linac
N. Valles and M. Liepe; Proceedings of the 2009 International Workshop of RF Superconductivity, Berlin, Germany (2009)

Baseline Center Cells

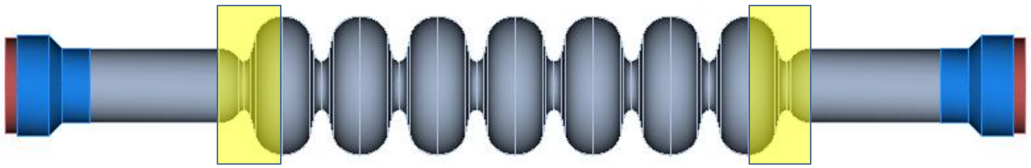


Enhanced cell-to-cell coupling



Band	1.8 GHz	1.9 GHz	2.5 GHz	2.7 GHz	3.1 GHz	3.4 GHz
Baseline Design	192	95	31	277	55	10
New Design	188	73	107	227	47	20

Optimization Constraints



- Minimize the **worst value** of $\xi_\lambda = \left(\frac{R}{Q}\right)_\lambda \frac{\sqrt{Q_\lambda}}{f_\lambda}$ over all dipole HOM passbands up to 10 GHz (worst mode matters!)
- Constraints
  - Maintain Epk/Eacc < 2.1
  - Keep Hpk/Eacc < 4.2 mT/(MV/m)
  - Limit wall angle to 85^o
  - Limit radius of curvature to 6 mm
  - Maintain high fundamental mode R/Q x G (Maximal reduction < 5%)
- Design Validation
  - Cavity's optimized properties should be preserved for realistically shaped cavities (machining variation)

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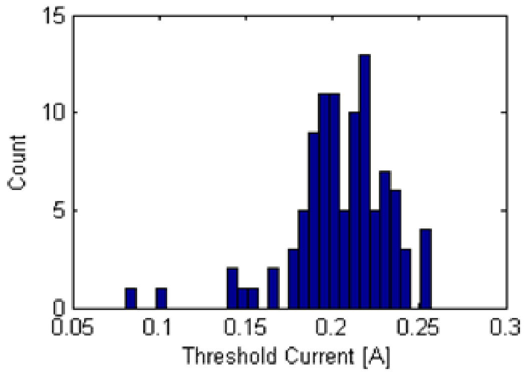
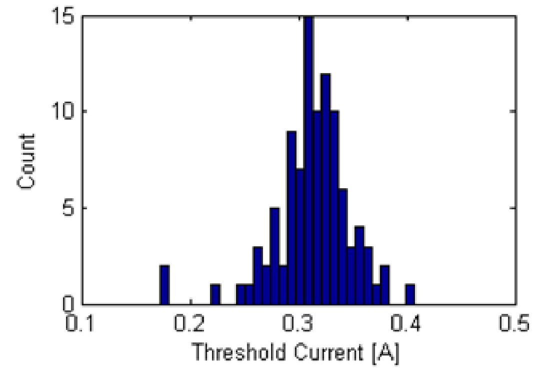
BBU Simulations

Optimize Cavity W.R.T. BBU parameter → Introduce realistic shape variations (x400/error) → Compute dipole HOMs to 10 GHz (1692 modes /cavity) → Generate realistic ERL (x100) → Compute BBU current

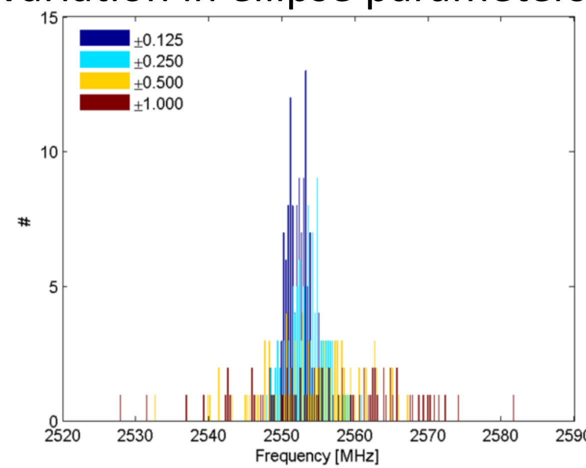
± 0.125 mm error



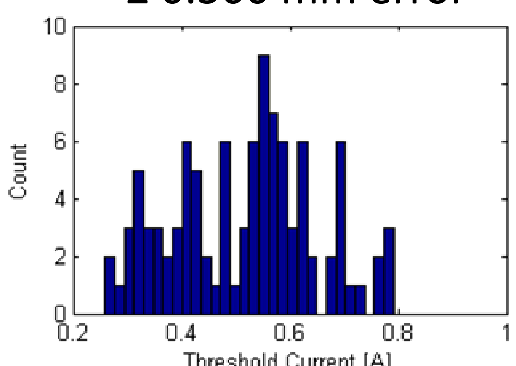
± 0.250 mm error



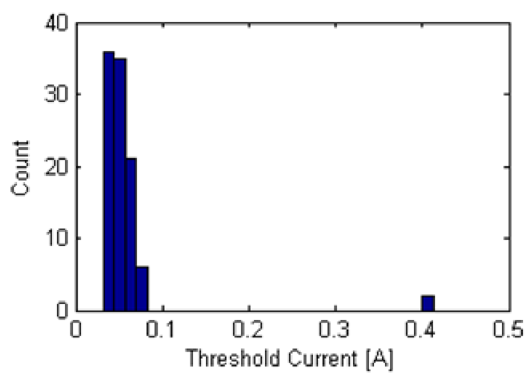
Variation in ellipse parameters



± 0.500 mm error



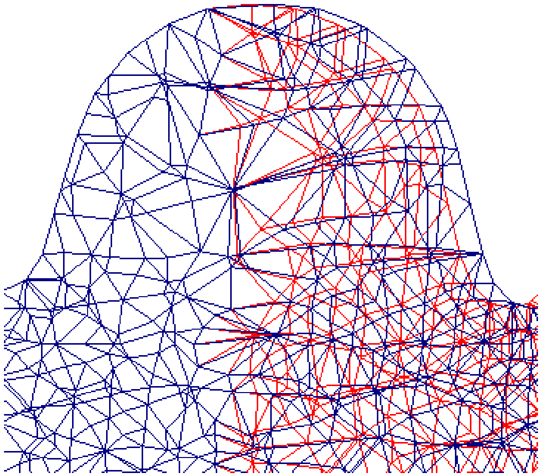
± 1.000 mm error



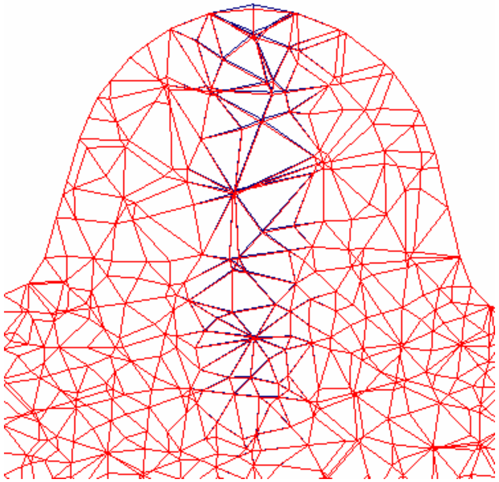
Loosened machining tolerances increase relative cavity-to-cavity HOM frequency spread (good!)

Beam Break-Up Studies for Cornell's Energy Recovery Linac.
N. Valles, D. S. Klein and M. Liepe; SRF 2011

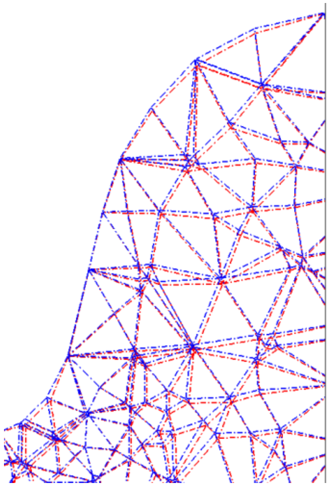
BBU Simulations

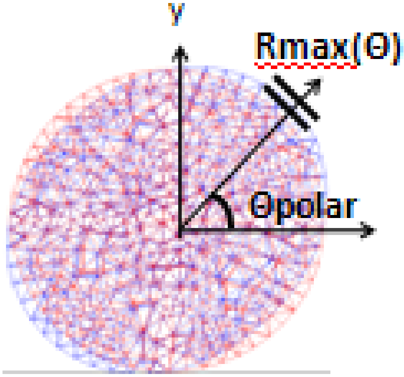


Cell Length Error

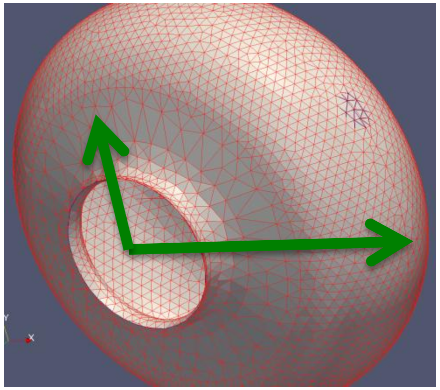


Cell Radius Error

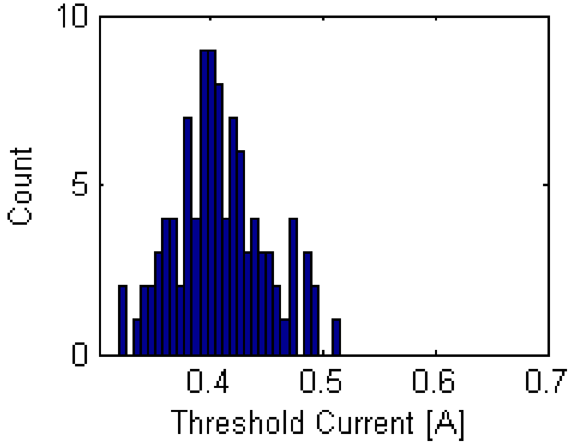




Elliptically Deformed Cell



Cell with Bump



Effects of Elliptically Deformed Cell Shape in the Cornell ERL Cavity
L. Xiao, K. Ko, K. Lee, M. Liepe and N. Valles; SRF 2011.

Coupler Kick Studies

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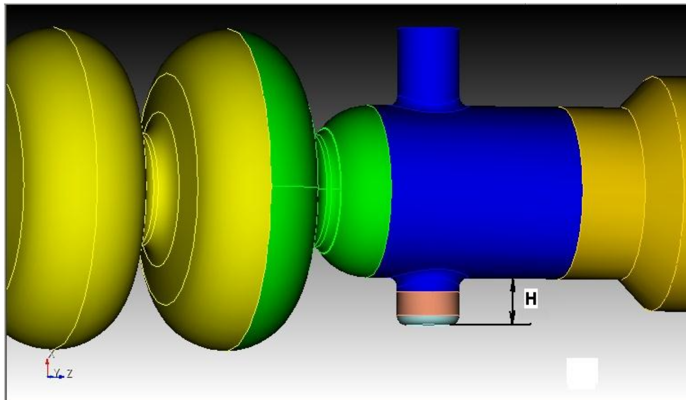
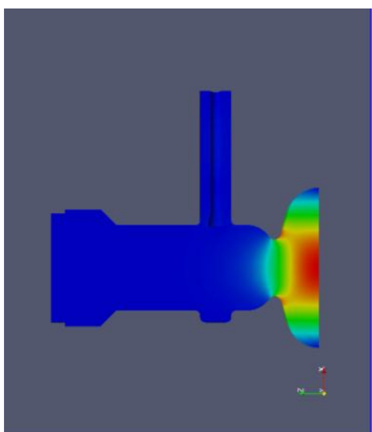
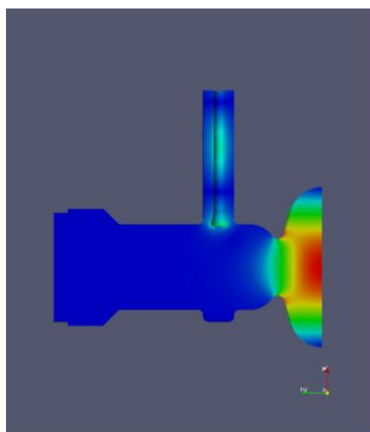


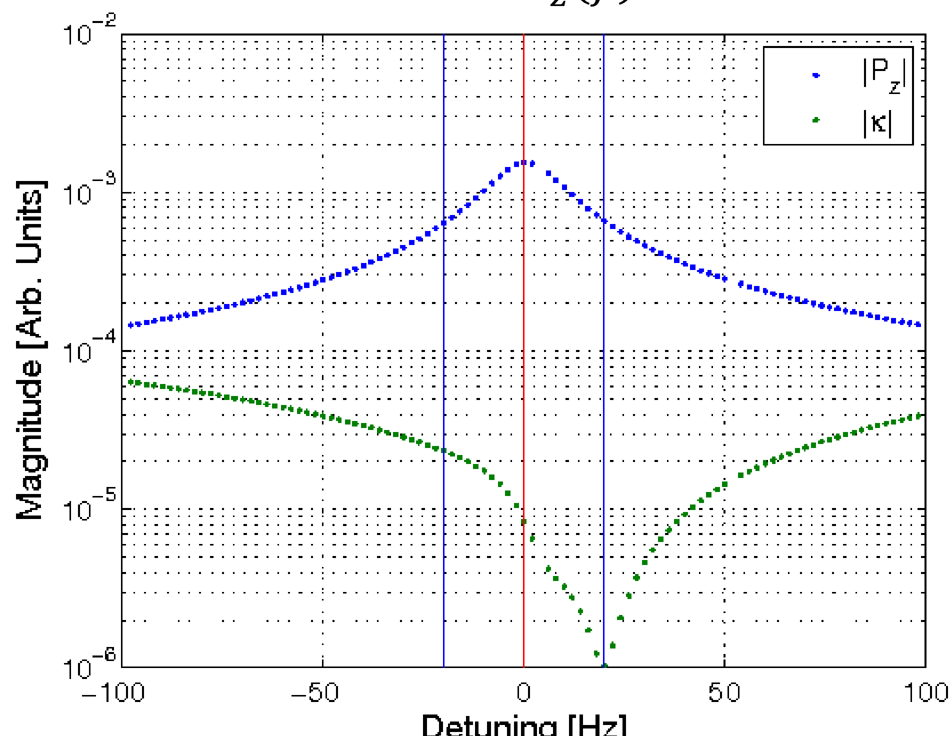
$$\begin{pmatrix} P_x \\ P_y \\ P_z \end{pmatrix} = \frac{q}{c} \int \begin{pmatrix} E_x \cos(kz) - cB_y \sin(kz) \\ E_y \cos(kz) + cB_x \sin(kz) \\ E_z \cos(kz) \end{pmatrix} dz$$

$$\kappa(f)^2 = \frac{P_x(f)^2 + P_y(f)^2}{P_z(f)^2}$$





On resonance **Resonance + 14 kHz**



Coupler Kick Studies in Cornell's 7-Cell Superconducting Cavities.
N. Valles, M. Liepe and V. D. Shemelin. SRF 2011

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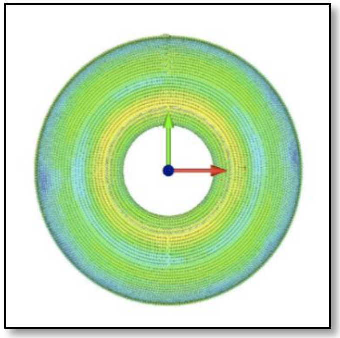
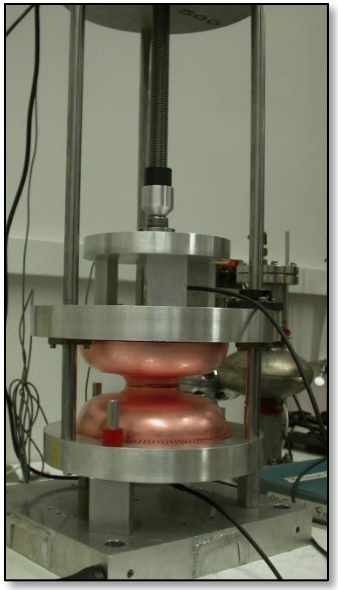
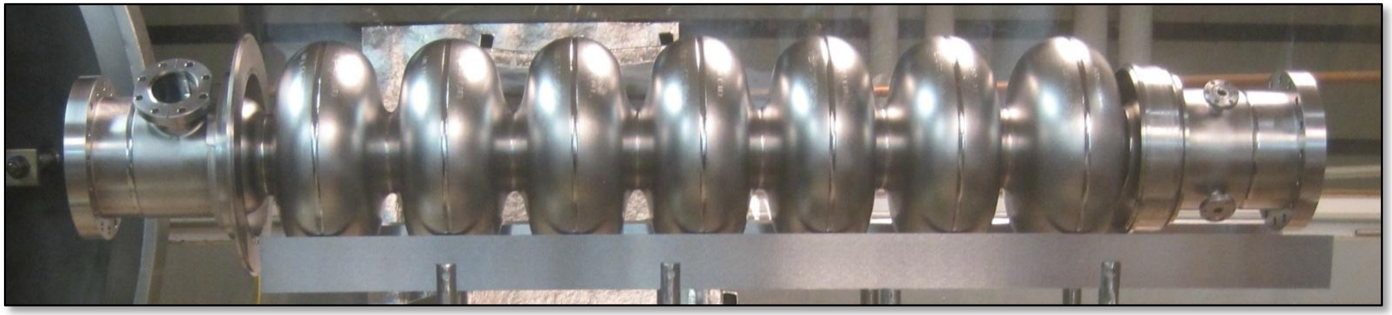
Cornell ERL 7-cell Fabrication

- Fabricated with 85% field flatness
- CMM results show that we achieved ¼ mm shape precision after welding
- Tuned to 95% field flatness
- Received high-Q treatment







Horizontal Test Cryomodule

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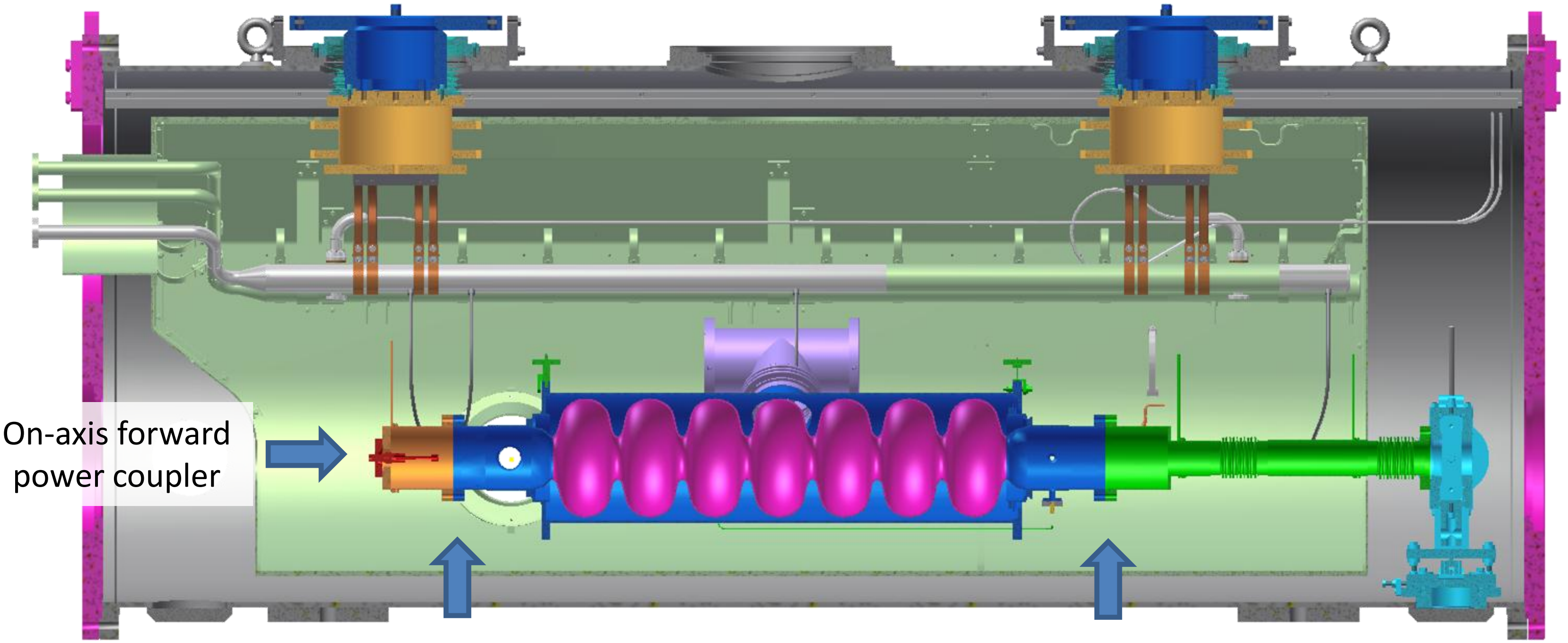
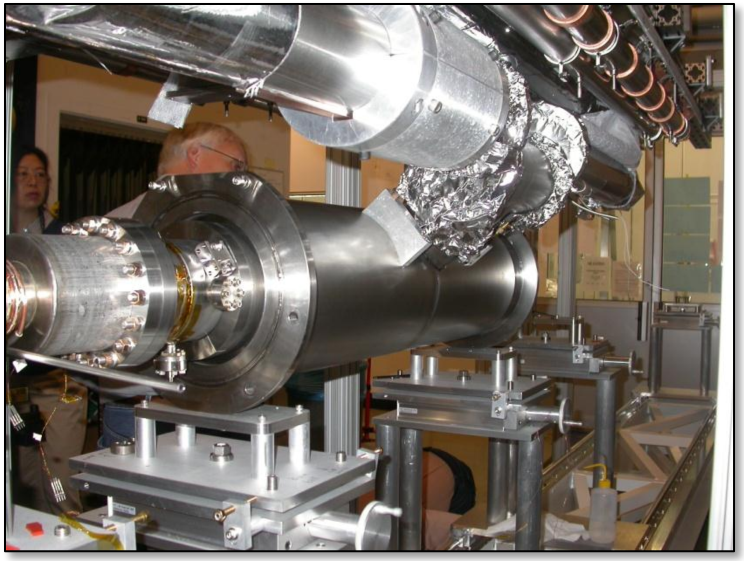


No HOM absorbing loads installed for first horizontal test

HTC Assembly



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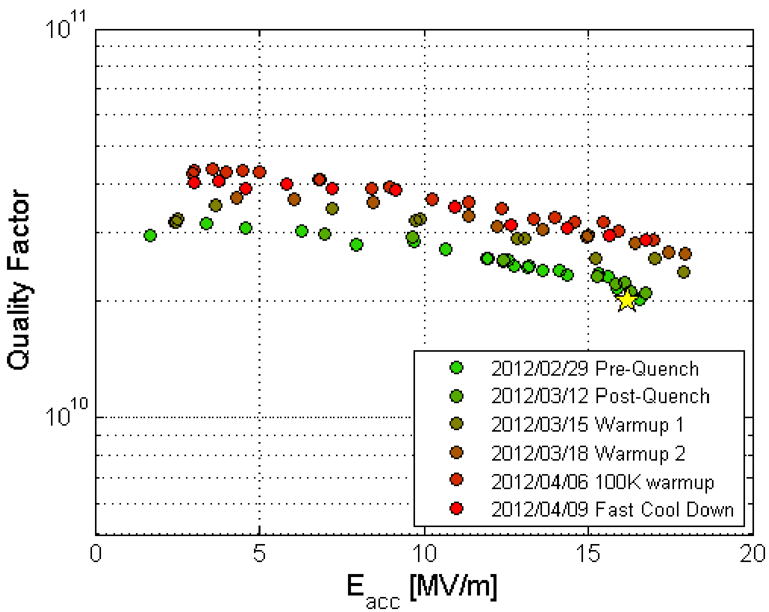
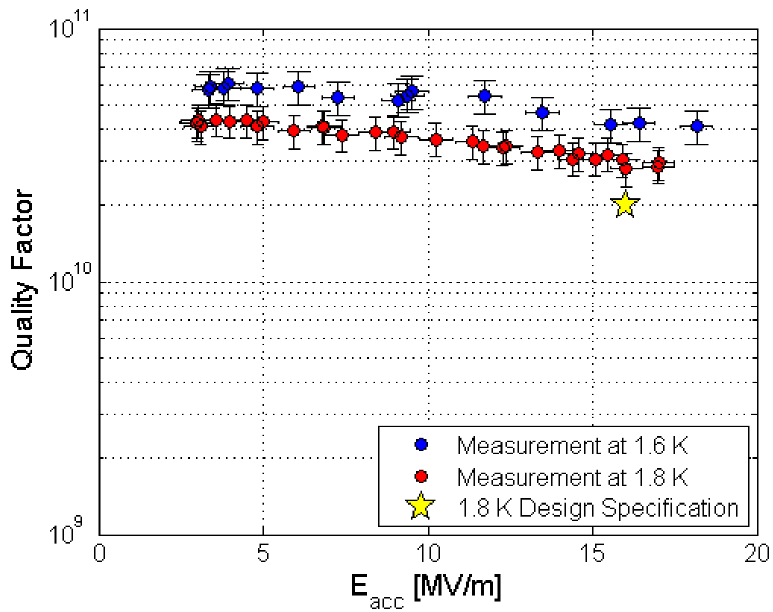
HTC-1 Results

Q vs Thermal Cycle

Final Q vs E Results

1.8 K





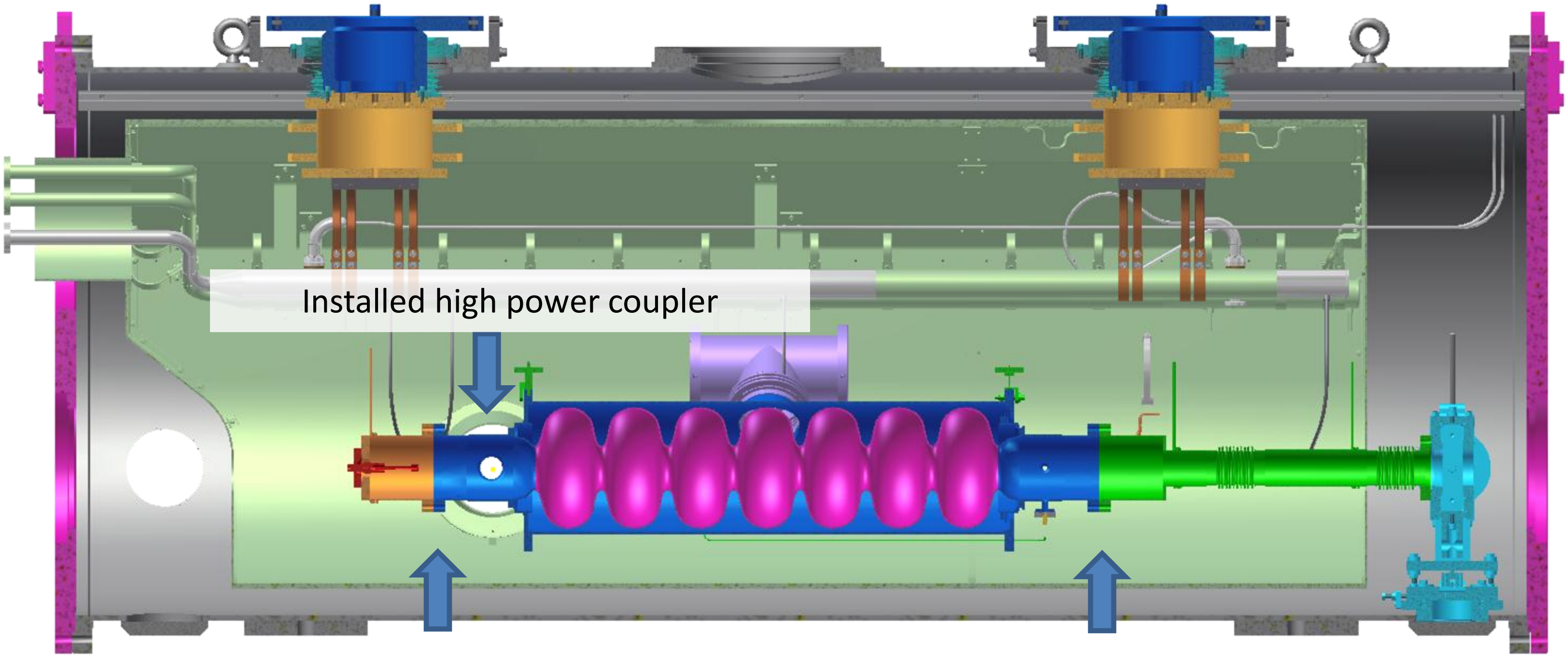
$Q_o(1.8\text{ K}, 16.2\text{ MV/m}) = 3 \times 10^{10}$

$Q_o(1.6\text{ K}, 5.0\text{ MV/m}) = 6 \times 10^{10}$

$(R_{res} \sim 4.5\text{ n}\Omega)$

Testing of the Main-Linac Prototype Cavity in a Horizontal Test Cryomodule for the Cornell ERL
N. Valles, F. Furuta, G.M. Ge, Y. He, K.M.V. Ho, G.H. Hoffstaetter, M. Liepe, T.I. O'Connell, S. Posen, P. Quigley, J. Sears, M. Tigner, V. Veshcherevich; IPAC12

HTC-2



No HOM absorbing loads installed
for second horizontal test

HTC-2 Results

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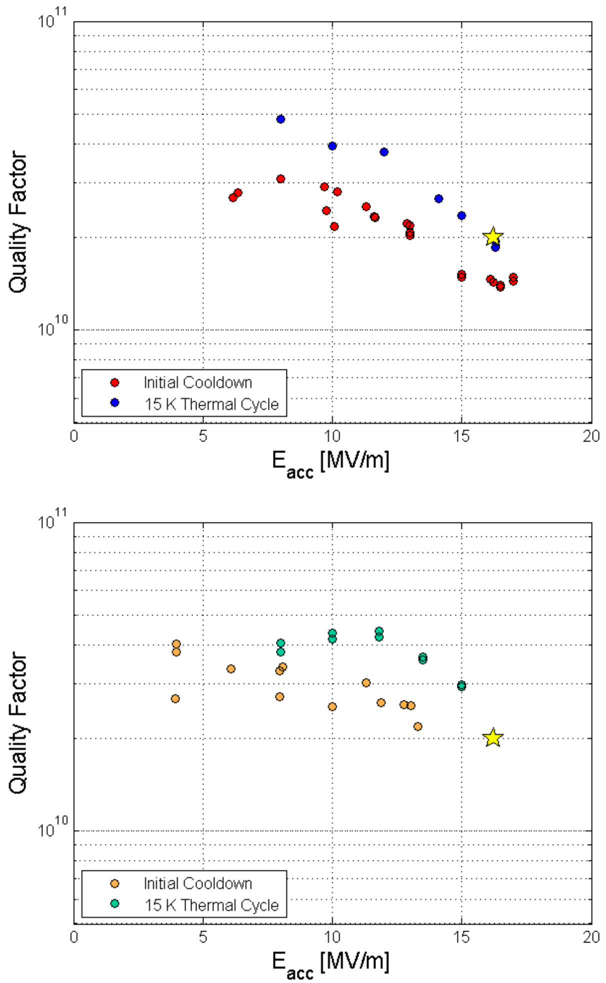
Q vs Thermal Cycle

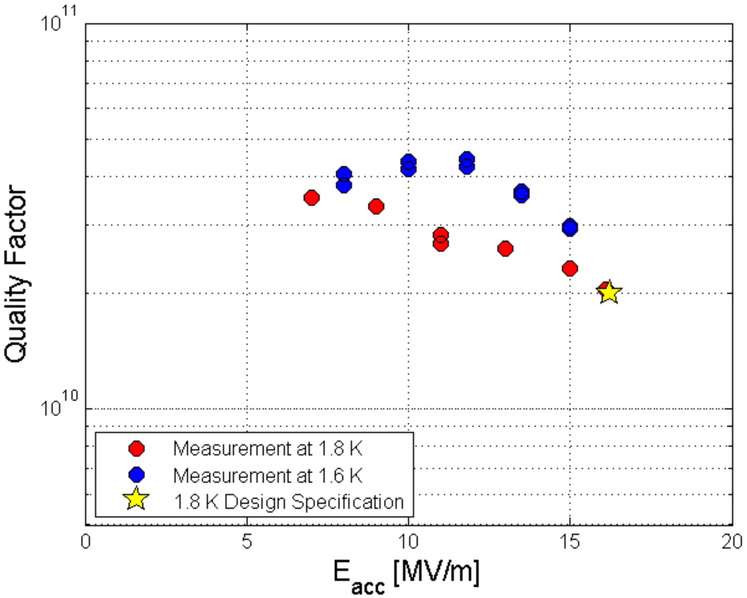
1.8 K

1.6 K



Q vs E Results

- Initial Qs lower than HTC-1
- Thermal cycle to 15 K increased Qs
- Meets ERL specification

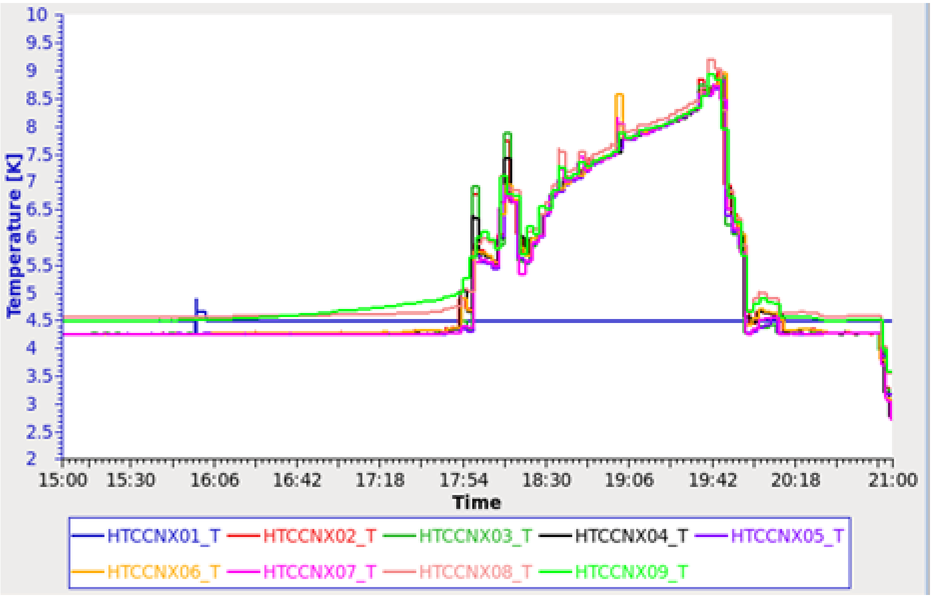


Thermal Cycling

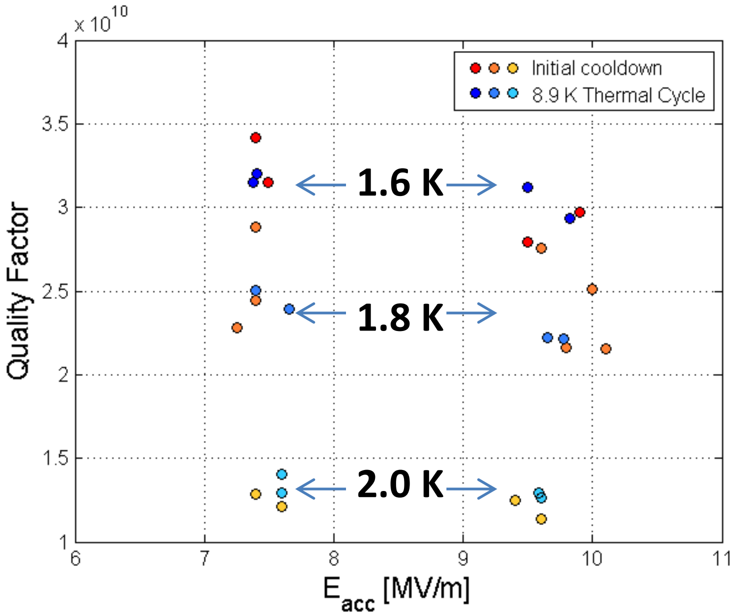
Elimination of residual flux via thermal gradients for $T < T_c$

Impact of trapped flux and thermal gradients on the SRF cavity quality factor
O. Kugeler, J. Vogt, J. Knobloch, S. Aull. IPAC12

- Thermal cycle increased center cell temp to 8.9 K



Comparison of HTC-2 low temp thermal cycle Q measurements



- No observed increase in Q after 8.9 K thermal cycle

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Conclusions

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- Successfully optimized cavity expected to achieve threshold currents between 300 – 500 mA under realistic conditions
  - Meets all optimization constraints
- Prototype ERL main linac 7-cell cavity has been fabricated
  - Exceeds very tight shape tolerance specifications
- **HTC-1:** The quality factor of the fundamental mode at 1.6 K has set a record for a multi-cell cavity installed in a horizontal cryomodule
  - Opens up the option to run at 1.6 K
- **HTC-2:** Quality factor, gradient specifications met
  - Investigations of benefits of thermal cycling suggest benefits occur in the 9.0 – 15 K range

Future Plans

- Preparations for HTC-3 underway. Two beamline HOM absorbers will be installed in the cryomodule
  - Scheduled for Spring 2013.
  - Tests will be run without beam
  - Tests in 2013 will include beam operation in Cornell ERL Injector which recently reached **65 mA CW**.
- Six additional 7-cell cavities under fabrication
  - Vertical tests starting November 2012
  - Goal: produce a full cryomodule in 2013 (tested in 2014)