Cornell Laboratory for
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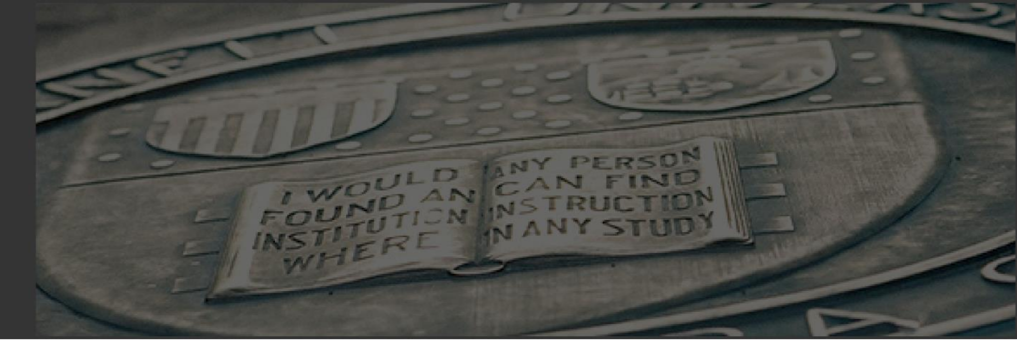
SRF2013 PARIS
16th International conference on RF Superconductivity



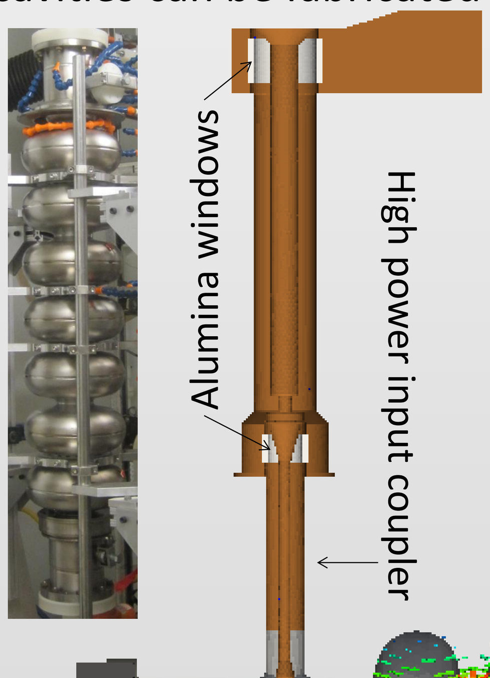
HOM Studies of the Cornell ERL Main Linac Cavity in the Horizontal Test Cryomodule

N. Valles, D. Goldman, G. H. Hoffstaetter, M. Liepe

Introduction

The main linac 7-cell cavity for Cornell's Energy Recovery Linac (ERL) is a 1.3 GHz structure optimized to maximize threshold current through the ERL. This was achieved by designing center and end cells that reduce the strength of dipole higher-order modes.

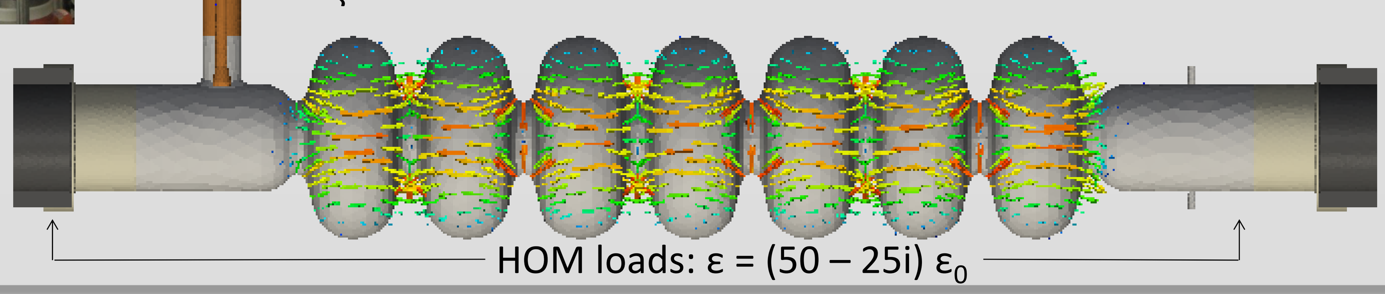
Simulations demonstrated that cavities within ±0.25 mm of the optimized value will yield an ERL with threshold current above 400 mA. It has been demonstrated that 7-cell cavities can be fabricated to within these tight tolerances.



This work investigates whether the properties of the higher-order mode (HOM) spectrum can be preserved from fabrication through installation in a cryomodule.

We characterize the cavity in 3 separate stages, incorporating axial coupler, high power coupler and HOM absorbers in the assembly.

The higher-order-mode (HOM) spectrum was measured in the HTC, and the mode properties compared with results from 2D and 3D codes[2, 3].

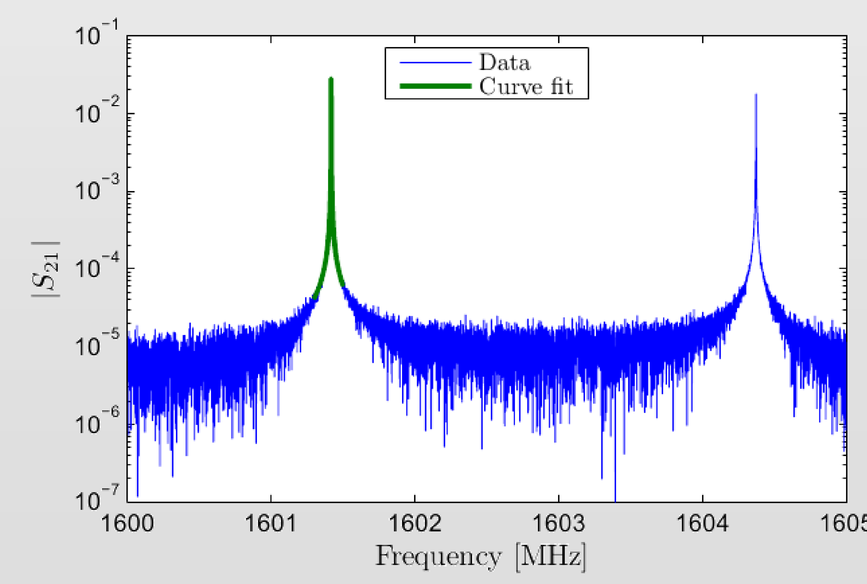


Mode Property Extraction

The two-port response of the cavity can be used to determine the resonant frequency (f_0) and loaded quality factor (Q_L) of the higher-order modes. Two methods of determining loaded quality factors were used to cross check results.

$|S_{21}|$ vs Frequency Method

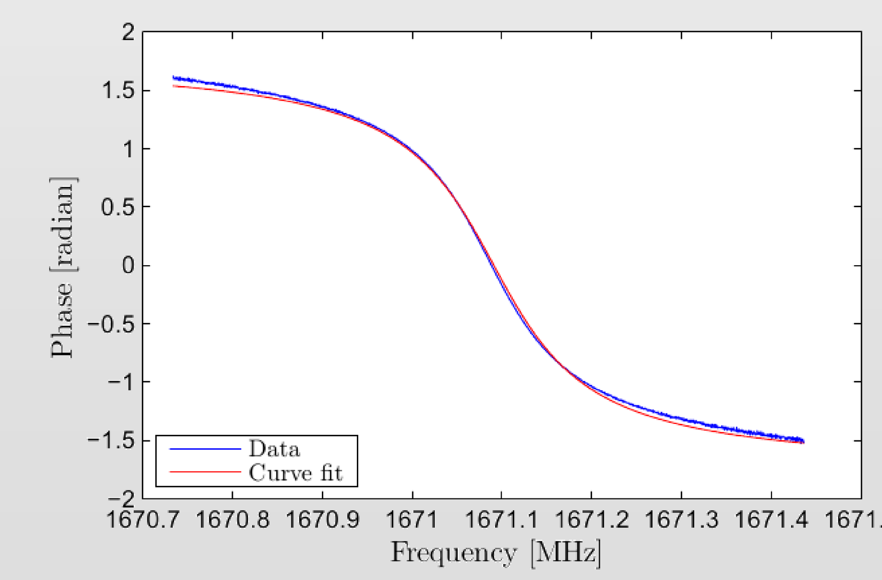
$$|S_{21}|^2(\omega) = \frac{|S_{21}(\omega_0)|^2}{Q_L^{-2} + \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)^2}$$



Measured $|S_{21}|$ vs Frequency and curve fit. Dipole mode has a f_o = 1601.419 MHz and Q_L = 7.97 x 10^6.

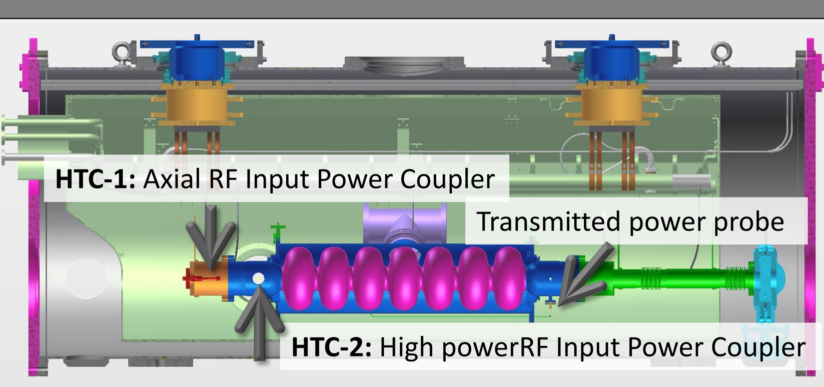
Phase vs Frequency Method

$$\phi(\omega) = \phi_0 + \tan^{-1}\left[Q \cdot \left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)\right]$$

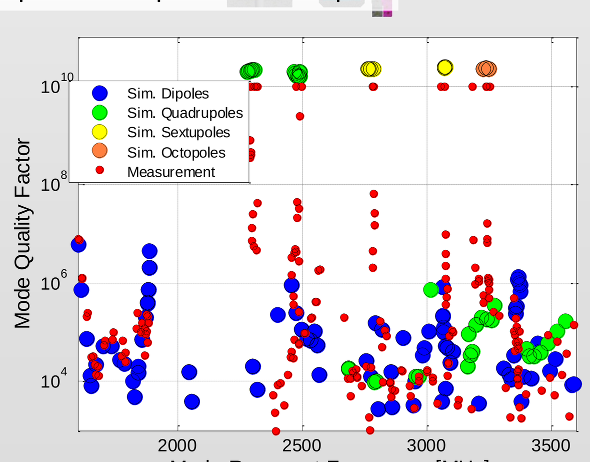


Measured Phase vs Frequency with curve fit. Dipole mode has a f_o = 1671.091 MHz and Q_L = 1.05 x 10^4.

HTC-1 and HTC-2 (without HOM loads)



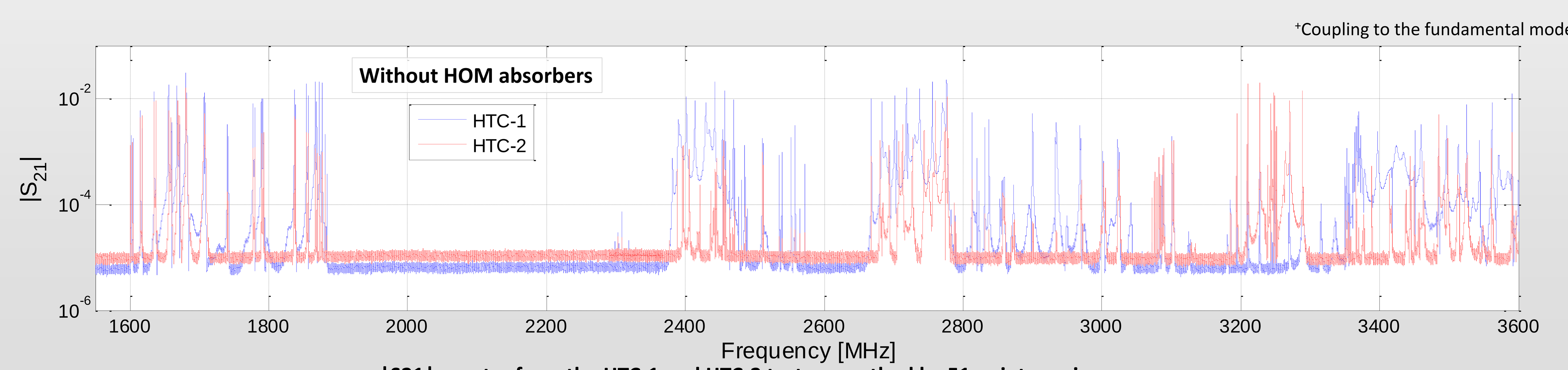
Right: Comparison of 2.5D simulation (assuming axial symmetry) and experiment of HTC-1 configuration. Lower Q's caused by broken symmetry of input coupler port.



The HOM spectrum was characterized via S-parameter measurements at each stage of the HTC tests. For HTC-1, the transfer function was measured between an axial RF power coupler (Q_{ext} = 8.9 x 10^{10})+ and a field probe on the opposite side of the cavity (Q_{ext} = 1.4 x 10^{11})+.

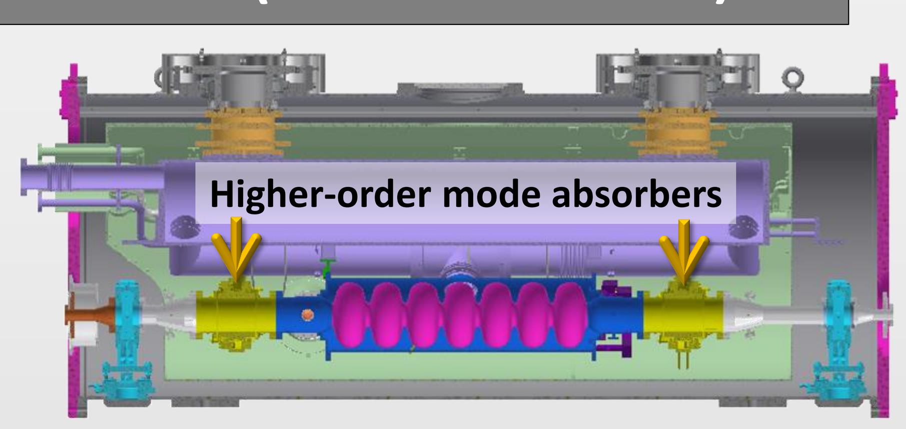
HTC-2, |S21| was measured from the side mounted input coupler (Q_{ext} = 4.5 x 10^7)+ to the field probe (Q_{ext} = 1.4 x 10^{11})+

+Coupling to the fundamental mode

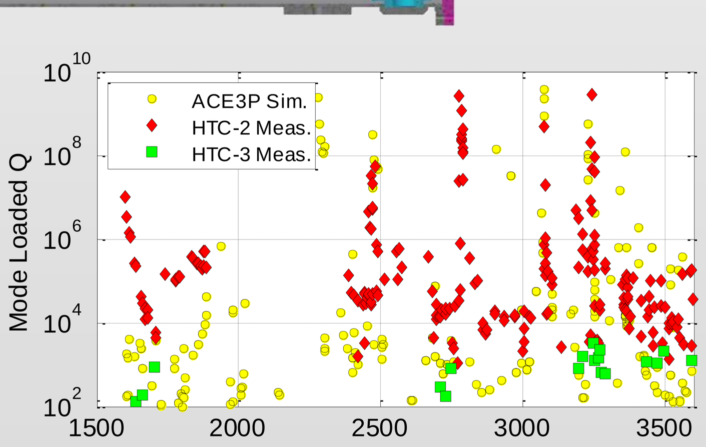


|S21| spectra from the HTC-1 and HTC-2 tests smoothed by 51 point moving average. High quality factors are due to the fact that there are no HOM loads installed in HTC-1 or HTC-2.

HTC-3 (with HOM loads)



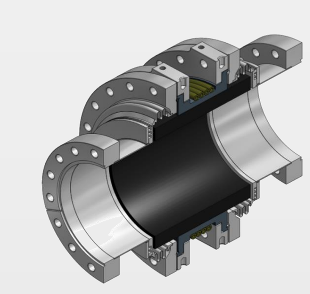
Right: Comparison of mode quality factors between HTC-2 and HTC-3, showing excellent damping of HOMs by beamline absorbers. ACE3P simulations include lossy HOM material and full coupler/waveguide assembly.



HTC-3 incorporated a high power input coupler and a beam line HOM absorber at each end of the cavity.

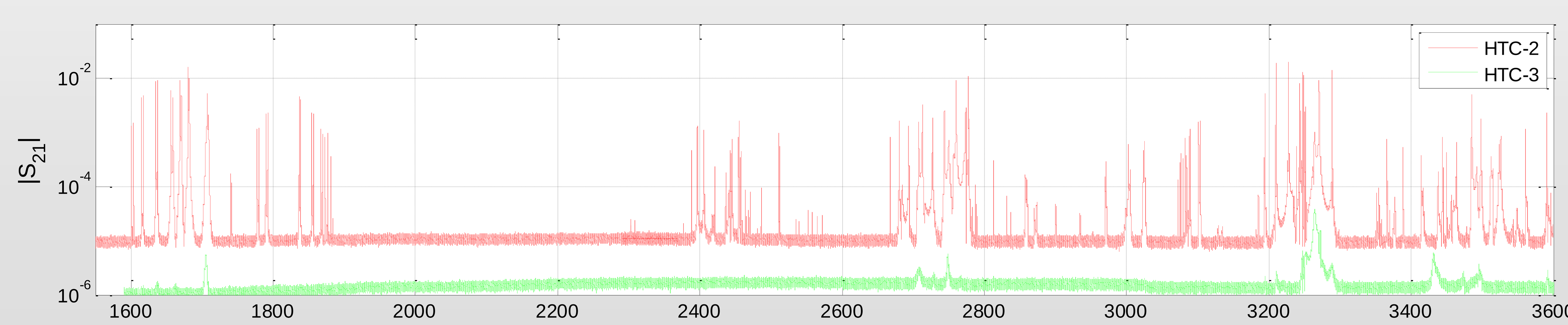
The HOM absorbers are made of SiC, with dielectric properties ε ~ (50 – 25i)ε_0, μ=μ_0.

The transfer function of the cavity was measured from the side mounted input coupler (Q_{ext} = 5.0 x 10^7) to a field probe on the opposite side of the cavity (Q_{ext} = 3.2 x 10^{11}). Q_{ext} quoted for the fundamental mode.



HOM Features

- Good DC conductivity at cryogenic temperatures
- Initial cold tests show efficient operation of helium cooling system.



|S21| spectra comparing HTC-2 and HTC-3 tests show strong HOM damping with SiC beamline absorbers

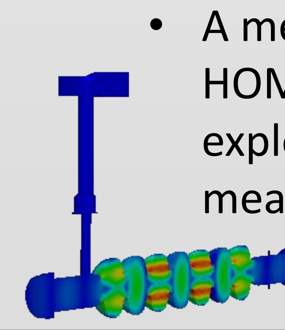
Results

- Quality factors of dipole modes are consistent with simulations, suggesting that the baseline cavity design properties are preserved.
- Quadrupole, sextupole and octopole passbands were measured at expected frequencies in HTC-1 and HTC-2. Broken symmetry causes these modes to have lower Q's than 2.5D simulations predict.
- Machining variation leads to varying HOM quality factors. Even so, Q's remain consistent with shape variation simulations performed on the optimized cavity geometry.[4]

[1] N. Valles, et al. "Testing of the main linac prototype cavity in a horizontal test cryomodule for the Cornell ERL," IPAC 2013
[2] Euclid TechLabs, http://www.euclidtechlabs.com/SLANS/slans.php
[3] L. Lee, Z. Li, C. Ng, and K. Ko, "Omega3P: A Parallel Finite-Element Eigenmode Analysis Code for Accelerator Cavities," SLAC-PUB-13529
[4] N. Valles, D. S. Klein and M. Liepe, "Beam Break-Up Studies for Cornell's Energy Recovery Linac" SRF 2011.
[5] N. Valles, M. G. Billing, M. Liepe, et al. "HOM Studies on the Cornell ERL Prototype Cavity in a Horizontal Test Cryomodule" IPAC 2012

Conclusions

- The first Cornell ERL main-linac 7-cell cavity has been successfully fabricated and tested in a fully equipped horizontal test cryomodule.
- The higher-order mode spectrum was measured with a network analyzer in all three configurations and preliminary analysis suggests HOMs are consistent with shape variation simulations, allowing high threshold current through the machine
- The beamline HOM absorbers provide strong broadband damping.
- **Fall 2013**: Will test cavity with beam from the Cornell ERL Injector.
  - A method to measure R/Q and frequency of HOMs via bunch charge modulation will be explored in these beam-based HOM measurements[5]



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Work supported by NSF Grants NSF DMR-0807731 and NSF PHY-1002467

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