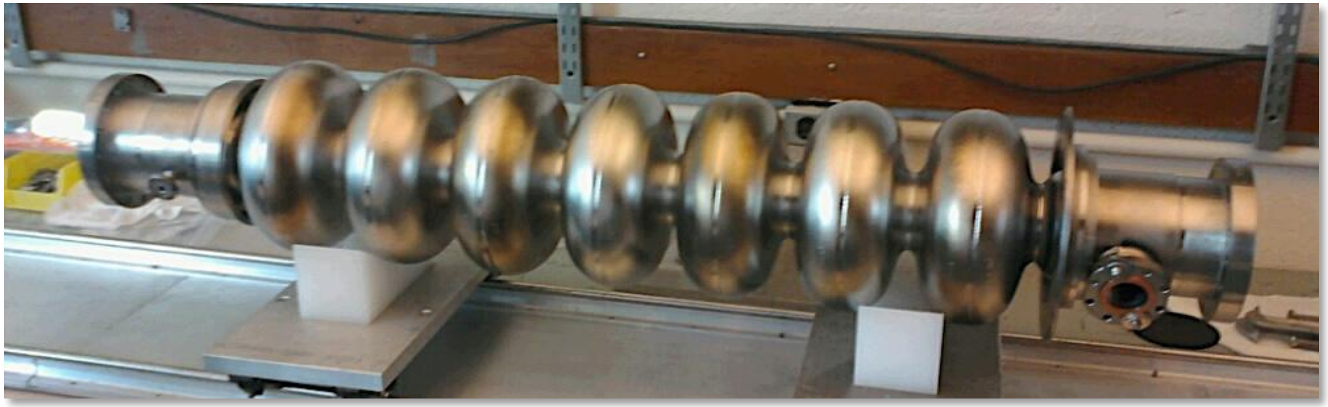
Cornell ERL's Main Linac Cavities



N. Valles for Cornell ERL Team

Overview

- RF Design Work
  - Cavity Design Considerations
  - Optimization Methods
  - Results
- Other Design Considerations
  - Coupler Kicks
  - Stiffening Rings, Mechanical Resonances
- Prototype Cavity Results
- Conclusions

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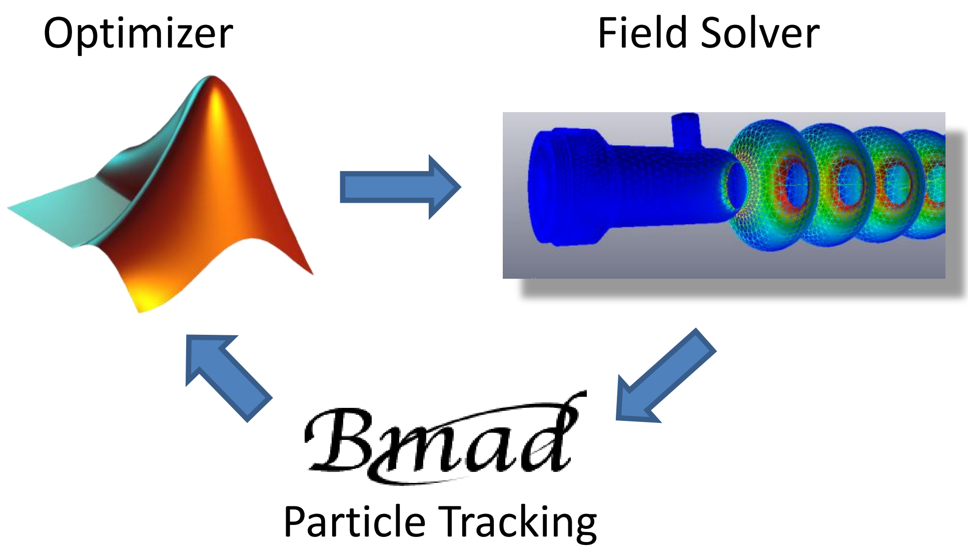
Cavity Design Goals

- Maximize Threshold Current through linac
  - Require > 100 mA at 77 pC bunch charge
- Minimize cryogenic losses due to fundamental
- Maintain low peak fields (Epk/Eacc < 2.1)
- Obtain robust design w.r.t. machining variation

Optimization Methods

Naïve Method



- Very computationally expensive!

Parallel Computing Resources Supported at Cornell's Center for Advanced Computing

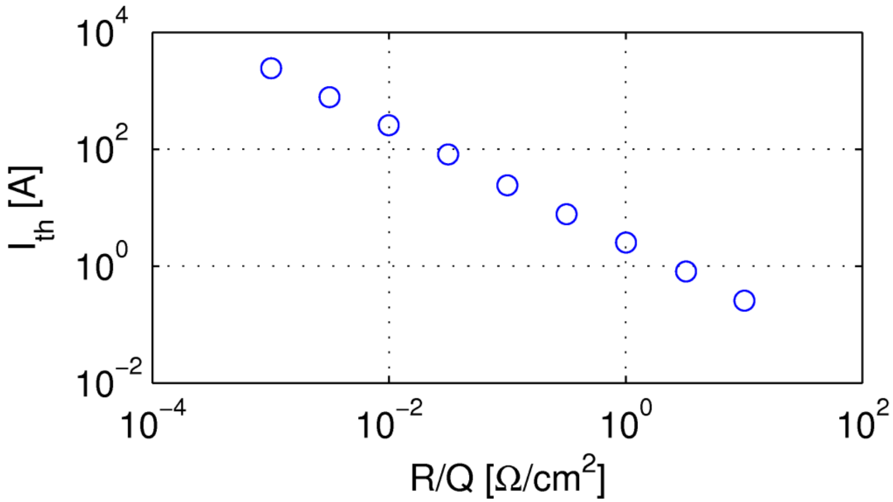
Better Method

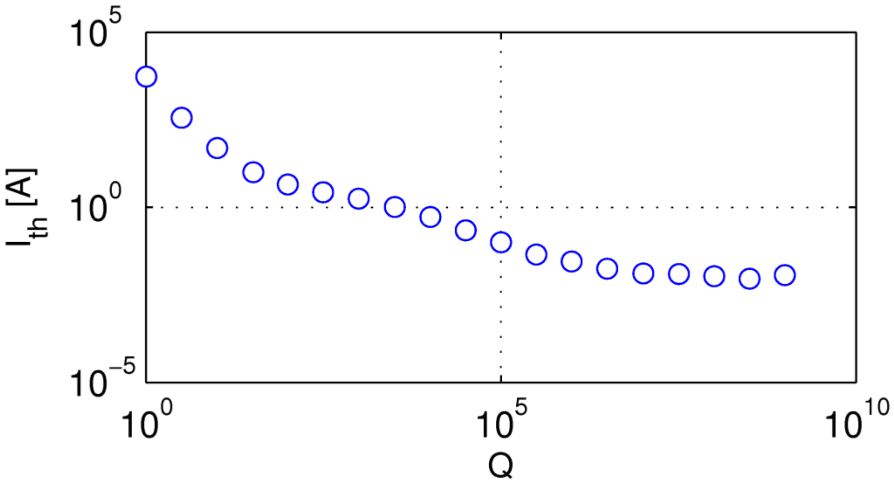
- Determine analytical goal function from scaling laws and optimize it
- Single cavity result

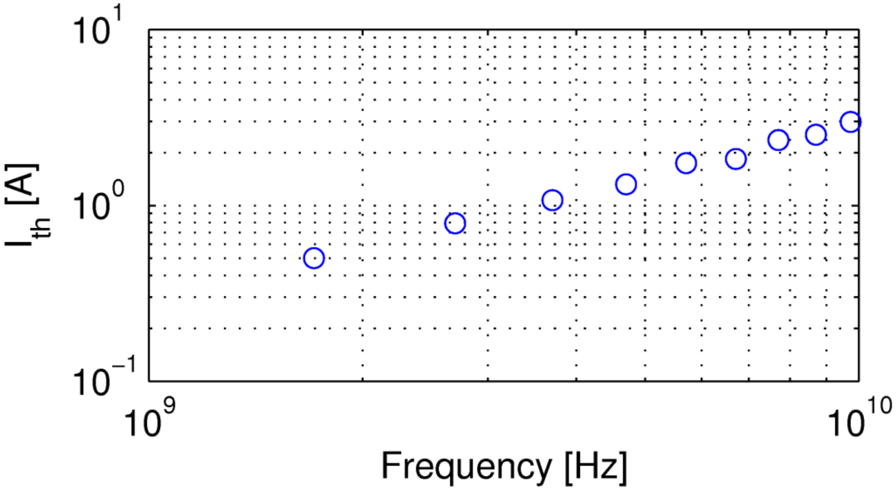
$$I_{th} \propto \frac{1}{\left(\frac{R}{Q}\right)_{\lambda} (Q_L)_{\lambda} \frac{1}{\omega_{\lambda}}} \cdot \frac{1}{T_{12}^{*} \sin(\omega_{\lambda} t_r)}$$

- Optimization then only requires a field solver, saving particle tracking as a verification of design
- Use parallel computing to speed optimization

Goal Function from Scaling Laws



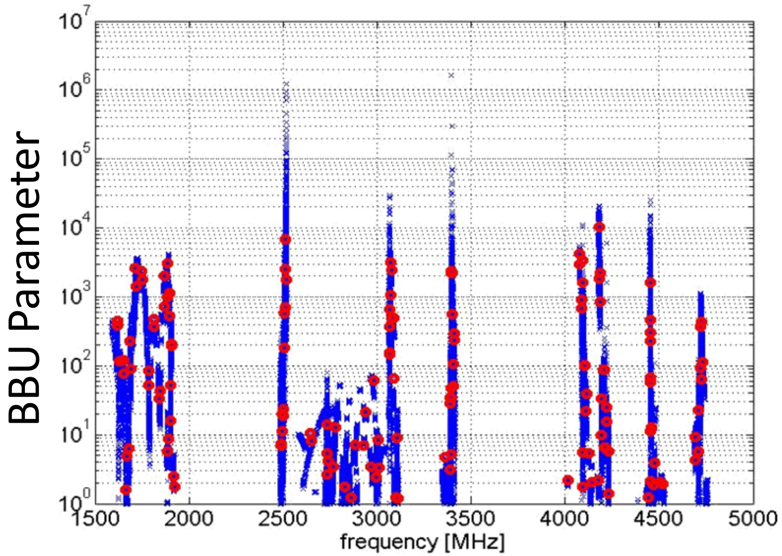




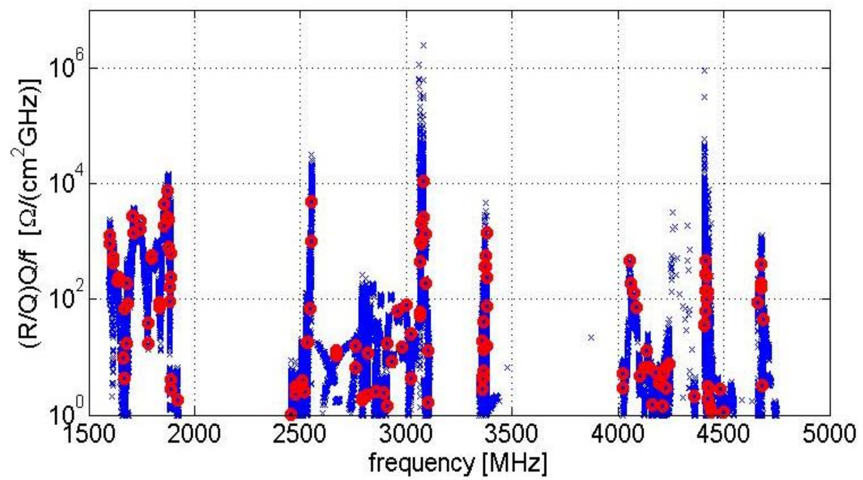
$$\zeta_\lambda = \left(\frac{R}{Q}\right)_\lambda \frac{\sqrt{Q_\lambda}}{f_\lambda}$$

Center-cell shape influence on BBU

Baseline Design



Center cells with increased cell-to-cell coupling

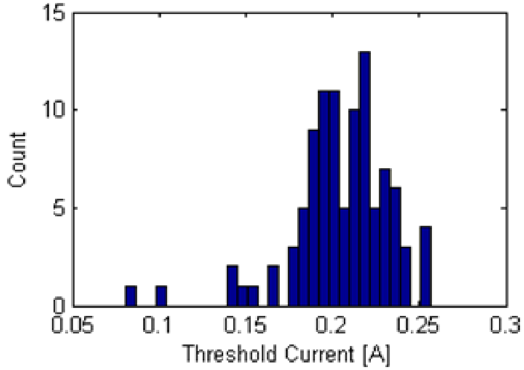


Increasing cell-to-cell coupling results in less variation of HOM properties for a given dimensional error, leading to increased threshold current through the linac.

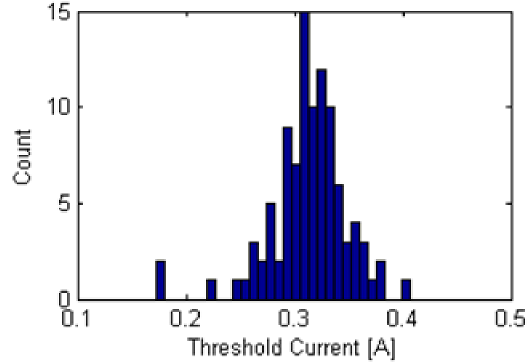
Beam-Break Up Simulations

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

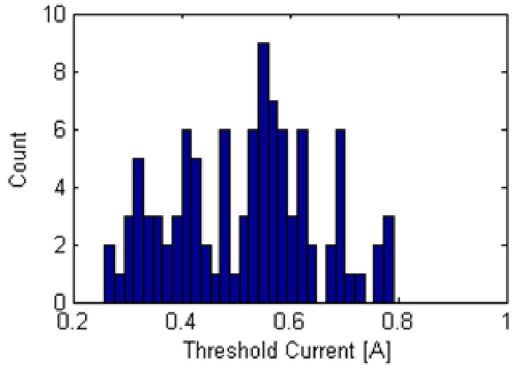
± 0.125 mm error



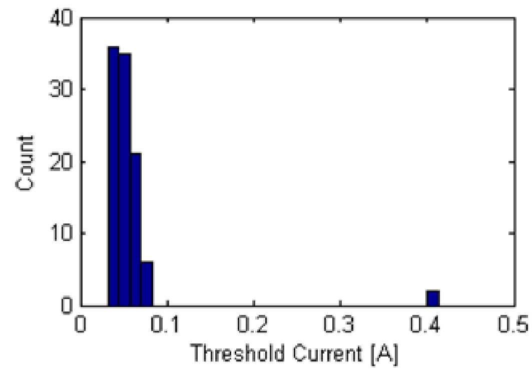
± 0.250 mm error



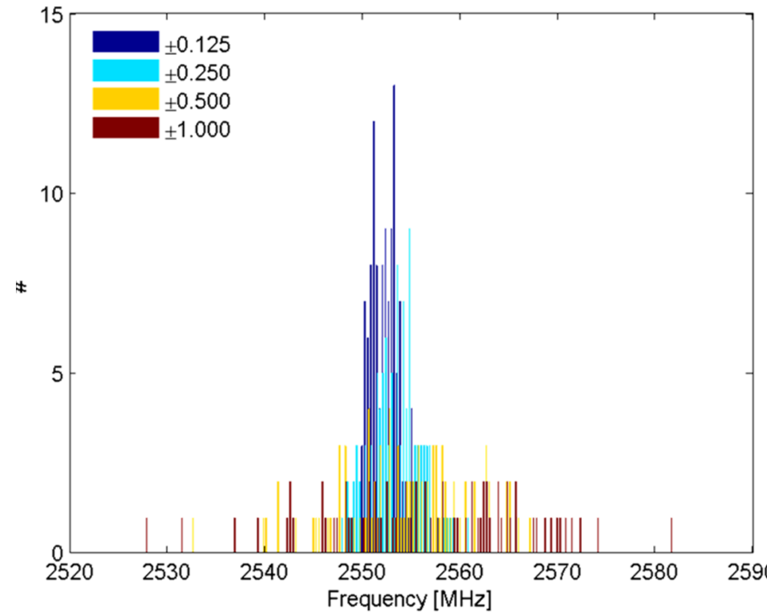
± 0.500 mm error



± 1.000 mm error

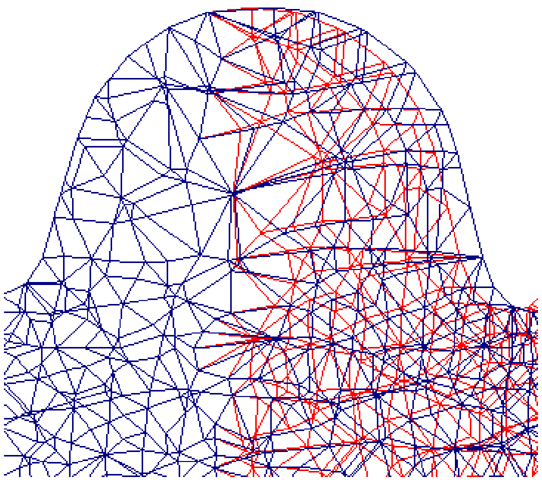


Variation in ellipse parameters

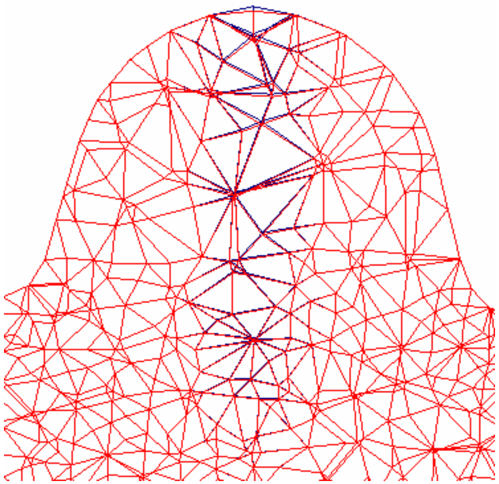


Loosened machining tolerances increase relative cavity-to-cavity frequency spread

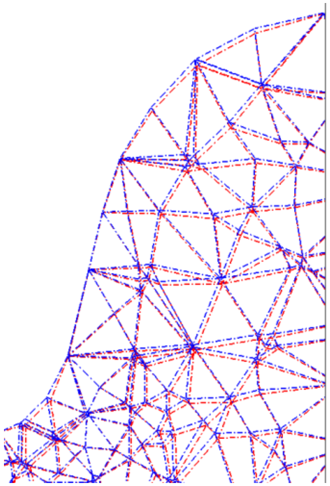
Specific Manufacturing Defects



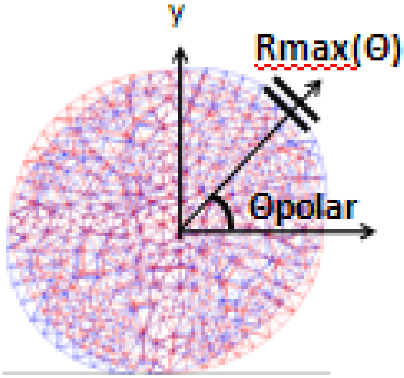
Cell Length Error



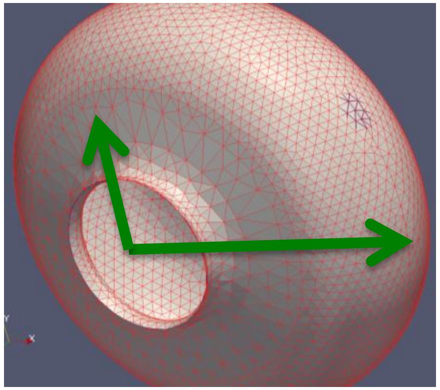
Cell Radius Error



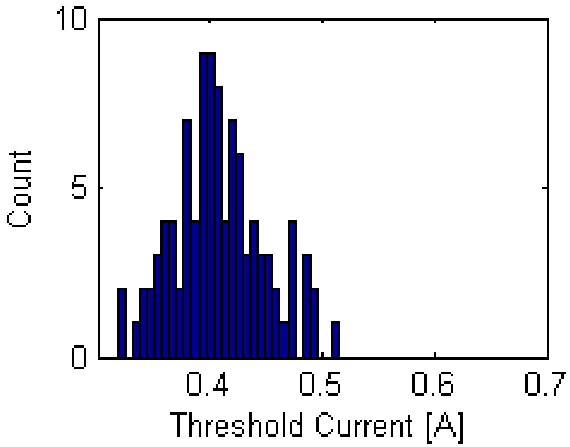
Deformed Cell Surface



Elliptically Deformed Cell

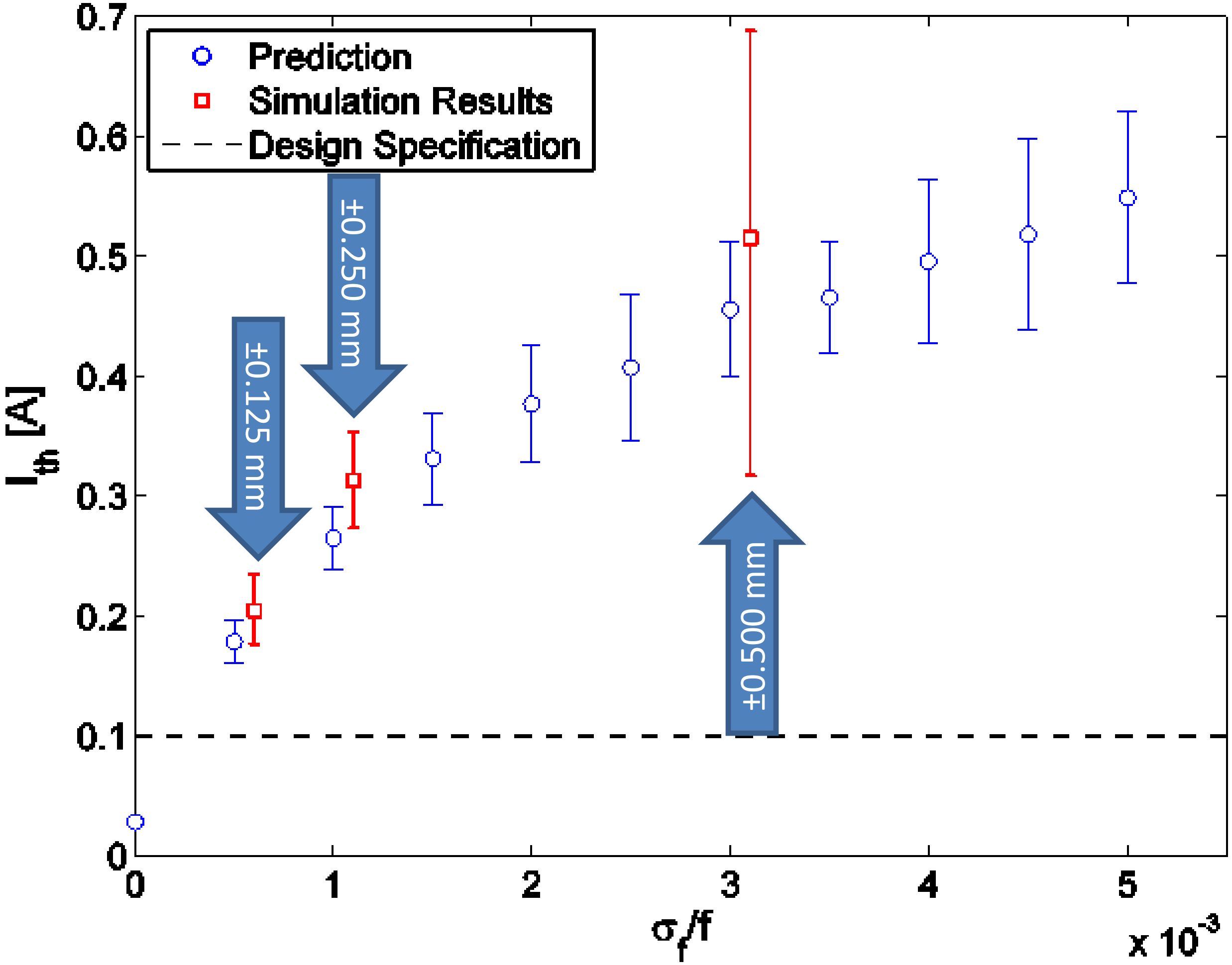


Cell with Bump



Liling Xiao, Kwok Ko, Ki Hwan Lee, Cho-Kuen Ng, SLAC, Menlo Park, U.S.A
Matthias Liepe, Nicholas Valles, Cornell University, Ithaca, NY, U.S.A

Threshold Current Results



Design Well Exceeds Cornell ERL Threshold Current Specification!

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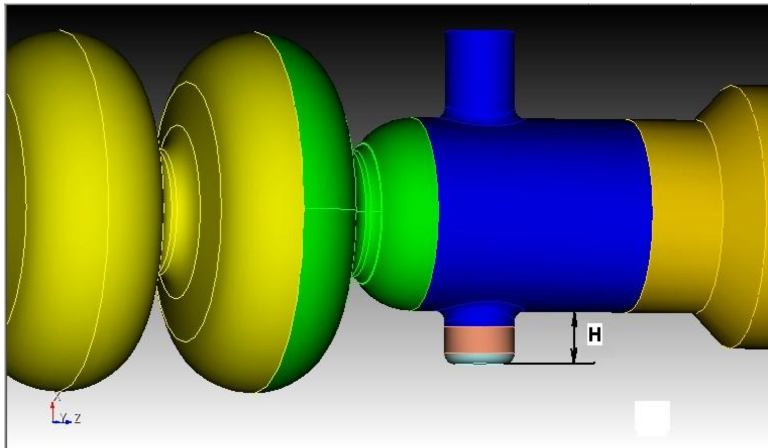
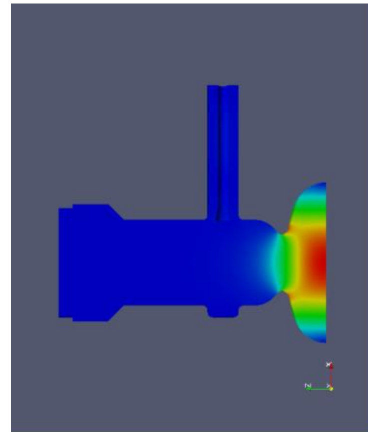
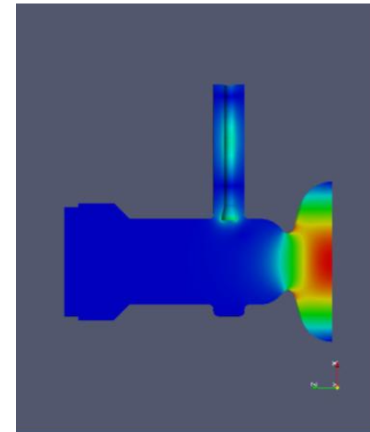
Coupler Kick Studies

Goal to minimize the effect of the coupler on the beam.
Necessary for low emittance operation.



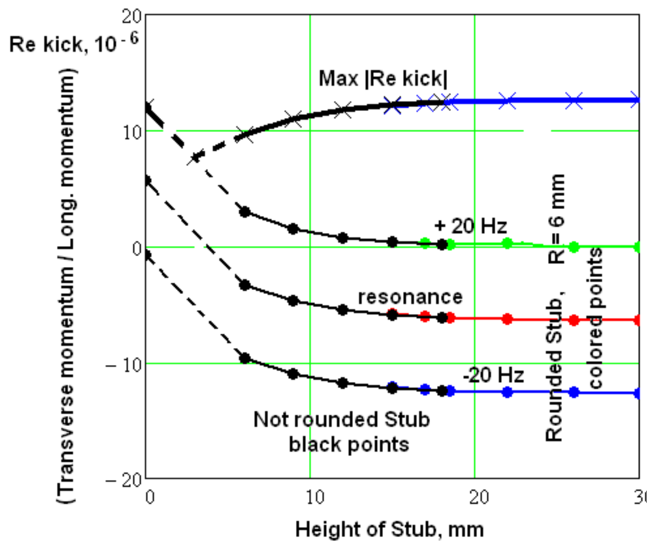


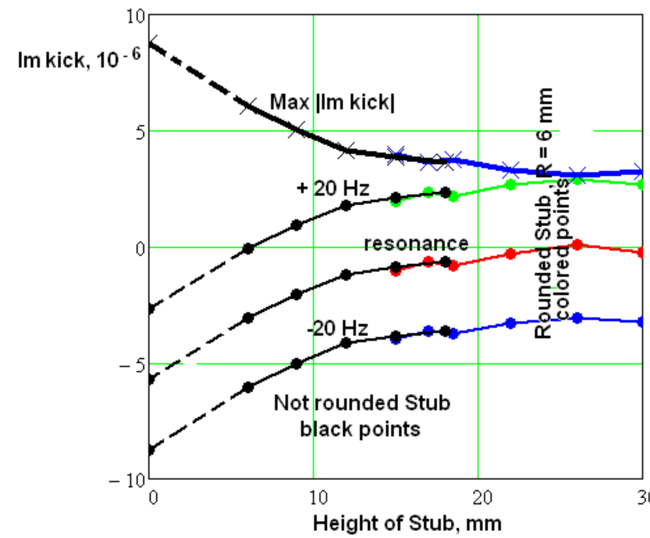
On resonance



Resonance + 14 kHz

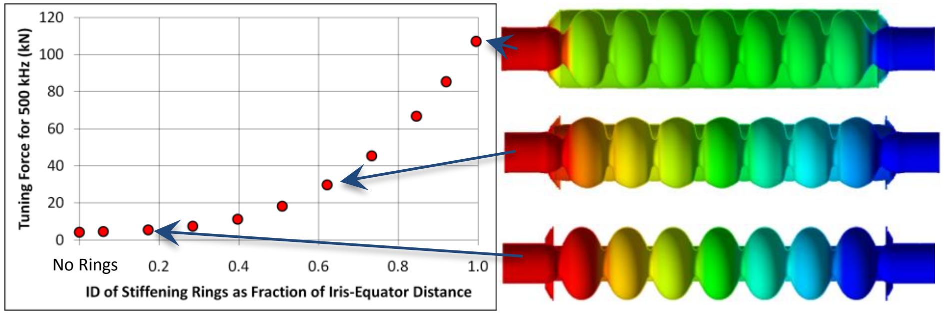
S3P calculations performed on NERSC cluster

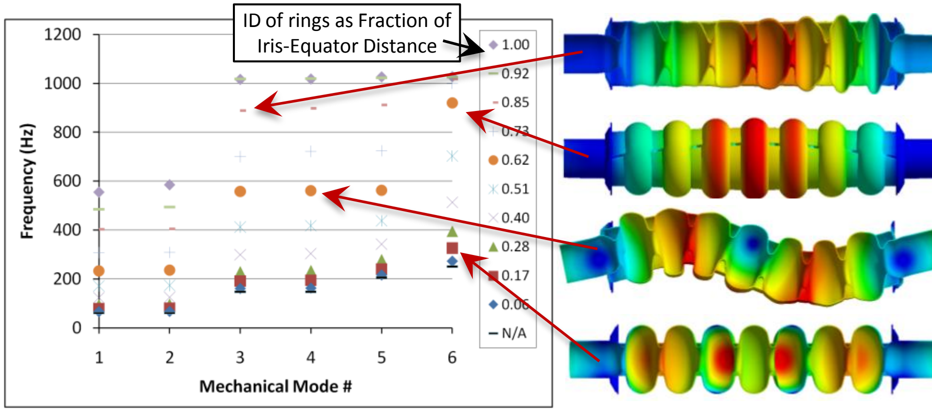


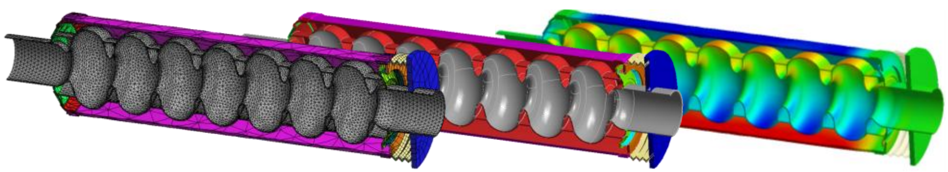


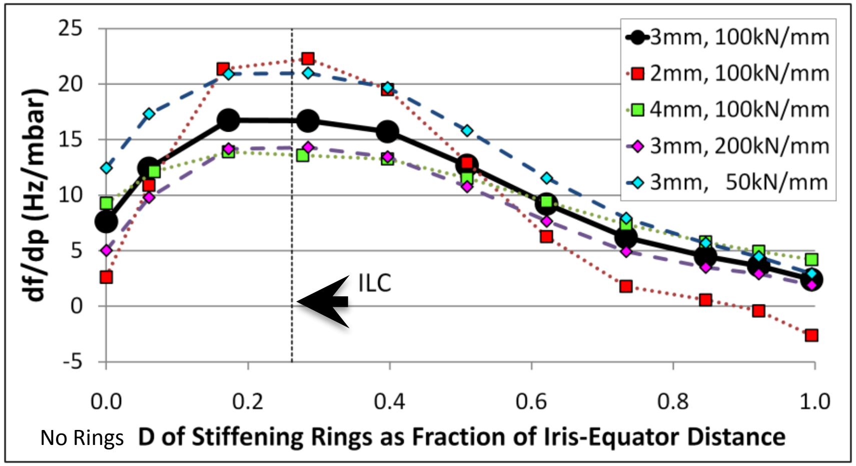
Minimizing Microphonics in Cavities

- Small bandwidth cavity vulnerable to detuning caused by microphonics, especially helium pressure fluctuations
- Diameter of cavity stiffening rings used as free parameter to reduce df/dp
- ANSYS simulations show that large diameter, small diameter, or no rings at all have smallest df/dp









- Tuner requirements rule out largest diameter stiffening rings
- Manufacturing easier with no rings
- Small/no rings make cavity fragile and lower mechanical resonant frequencies

Sam Posen

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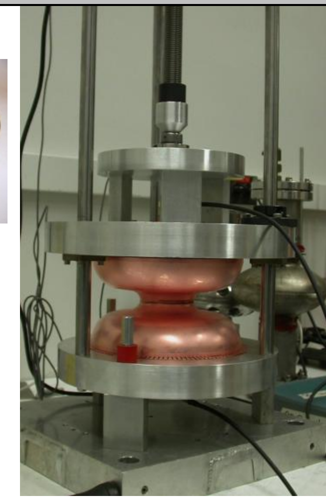
Prototype Cavity Fabrication

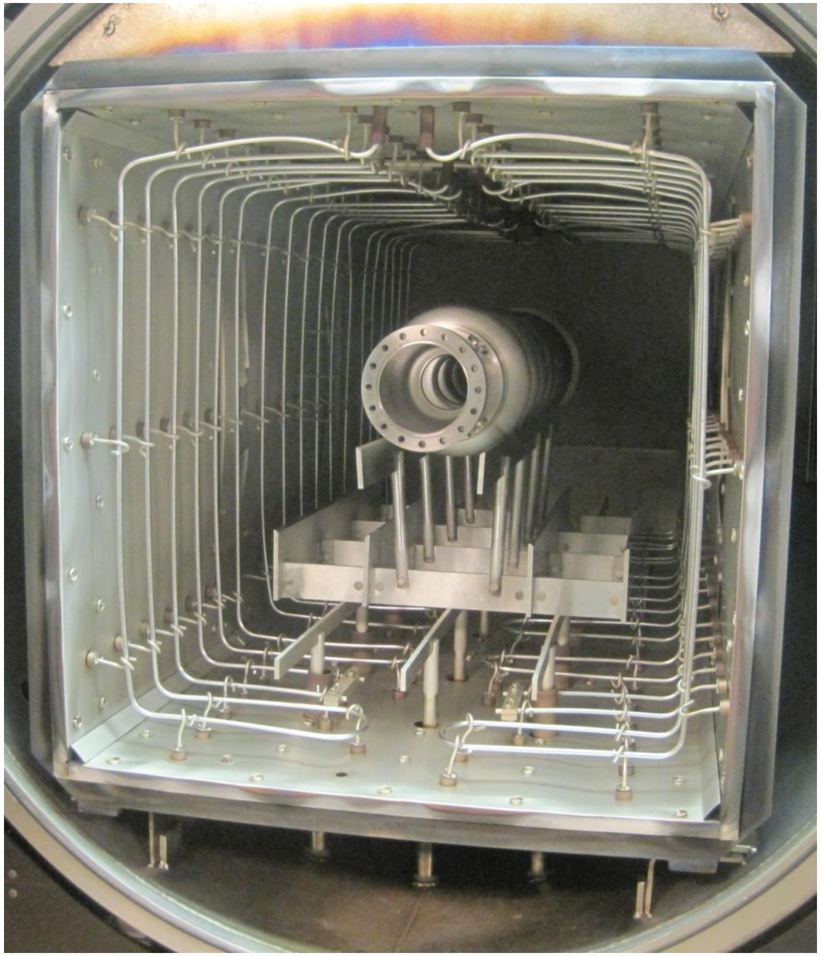
Quality control: CMM and frequency check



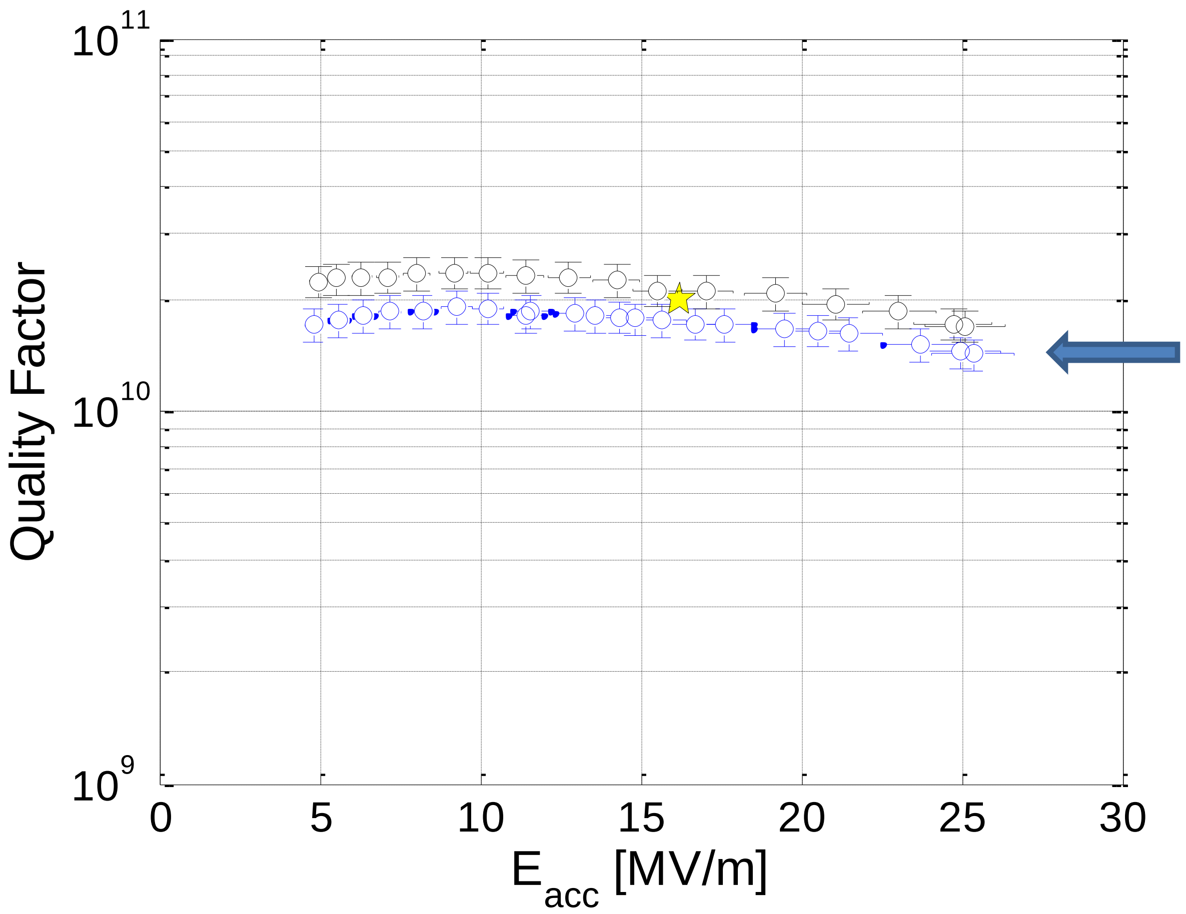
Finished main linac cavity with very tight (±0.250 mm) shape precision
⇒ important for supporting high currents (avoid risk of trapped HOMs!)

Prototype Cavity Pre-Test Treatment

- Fabricated with 85% field flatness
- Heavy BCP
- Outgassing (>600 C)
- Tuned to 95% field flatness
- Light BCP
- Ultrasonic cleaning
- HPR 16 hr
- 120^{o} bake 48 hr



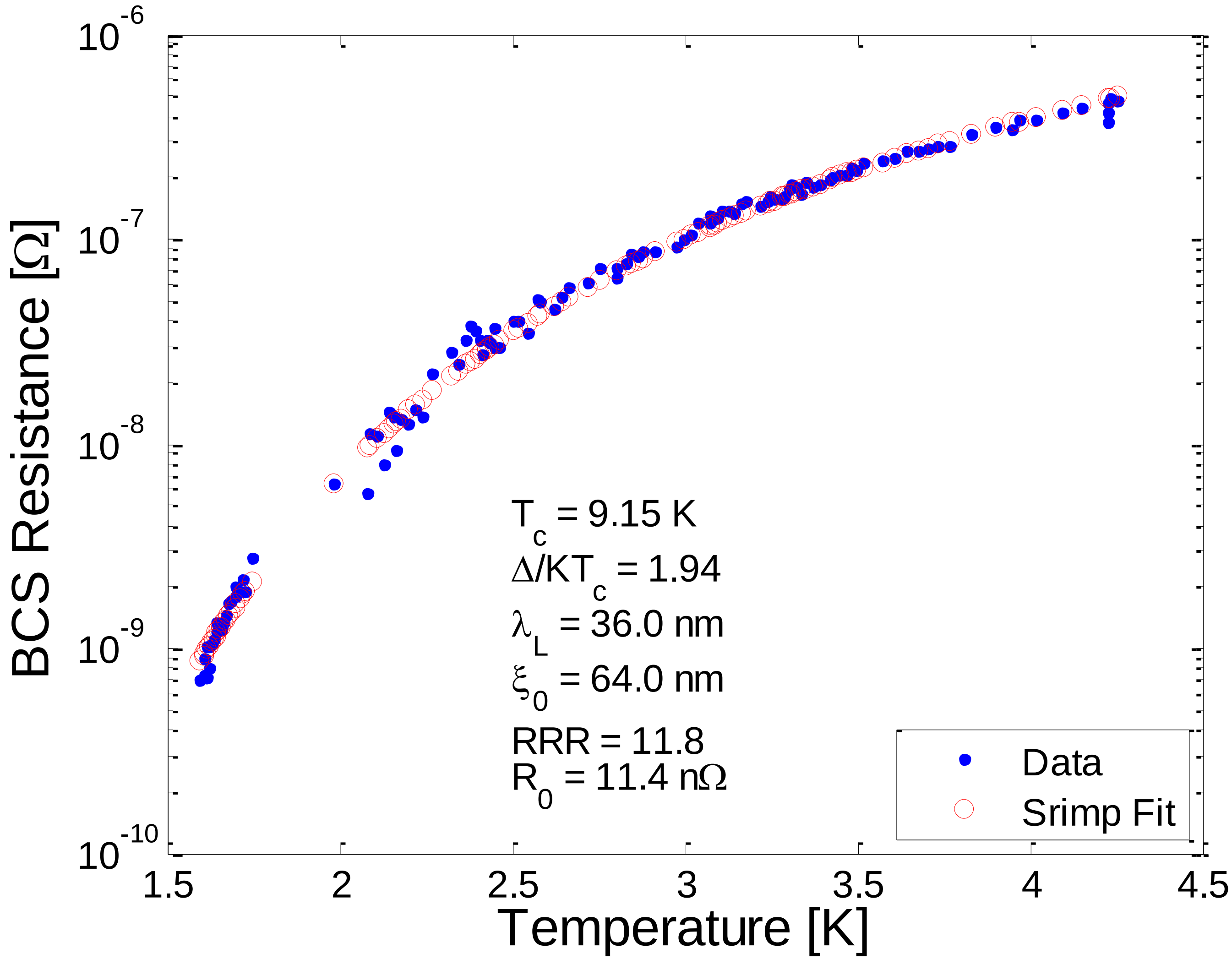
First CERL 7-Cell RF Test Results



Admin. Limited
No Radiation
No Quench

F. Furuta, A. Ganshyn, M. Ge, N. Valles
Cornell University 2011-Oct

Niobium Properties



F. Furuta, A. Ganshyn, M. Ge, N. Valles
Cornell University 2011-Oct

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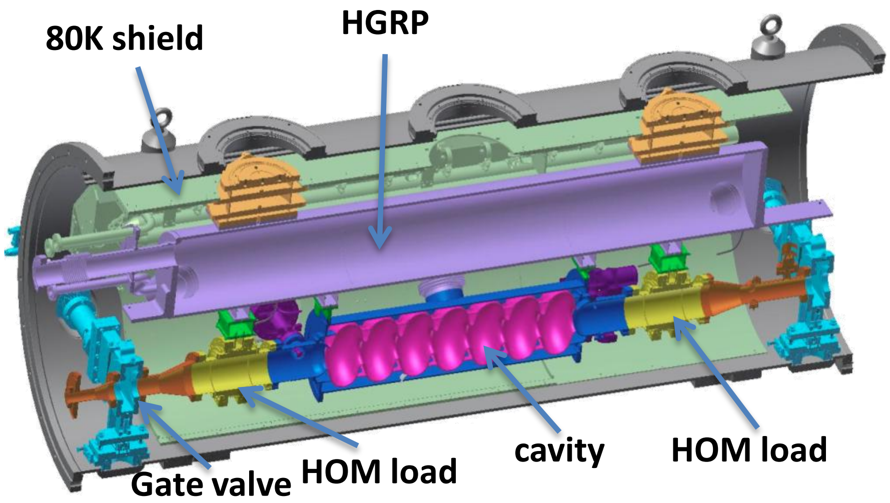
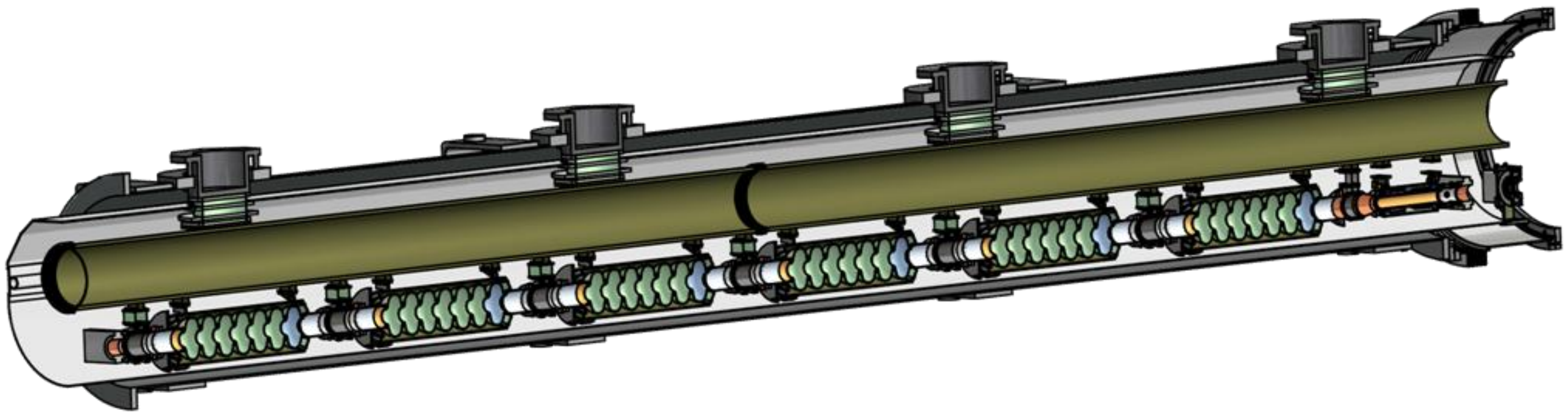
Conclusions

- The cavity design for the CERL main linac has been completed
  - Cavity design optimized with respect to beam-break up current
  - Simulations show linac supports > 400 mA current
  - Coupler kick and mechanical simulations are consistent with high quality beam requirements
- Prototype Cavity Fabricated and Tested
  - Fabrication: Cavity meets tight shape tolerances
  - RF Test: Cavity met specifications on first test
  - Next steps: maintaining performance with HOM absorbers and when in horizontal test cryostat

Next Steps: 2011 – 2014



- Test of prototype cavity without and with beam (up to 100 mA)
- Build and test full main linac SRF cryomodule



Thanks & References

Special Thanks to:

- ERL 2011 Committee
- Cornell SRF Group
- Cornell ERL Team
- SLAC Advanced Comp Group: L. Xiao, K. Ko, K. Lee, C. Ng
- Work supported by the NSF

For more information see:

Cornell ERL Research and Development C. E. Mayes , et. al. PAC 2011

Robustness of the Superconducting Multicell Cavity Design for the Cornell Energy Recovery Linac , M. Liepe, G.Q. Stedman, N. Valles PAC 2009

Seven-Cell Cavity Optimization for Cornell's Energy Recovery Linac ,
N. Valles and M. Liepe, SRF 2009

Baseline Cavity Design for Cornell's Energy Recovery Linac ,
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Cavity Design for Cornell's Energy Recovery Linac,
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Coupled Electromagnetic-Thermal-Mechanical Simulations of Superconducting RF Cavities, S. Posen, M. Liepe, N. Valles, IPAC 2010

Designing Multiple Cavity Classes for the Main Linac of Cornell's ERL
N. Valles and M. Liepe, PAC 2011

Effects of Elliptically Deformed Cell Shape in the Cornell ERL Cavity.
Liling Xiao, Kwok Ko, Ki Hwan Lee, Cho-Kuen Ng , Matthias Liepe, N. Valles , SRF 2011

Beam Break Up Studies for Cornell's Energy Recovery Linac.
N. Valles, Daniel Stuart Klein, Matthias Liepe. SRF 2011

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