Half-Reentrant Cavity Design, Fabrication, and Testing

Mandi Meidlinger

Michigan State University
National Superconducting Cyclotron Laboratory
East Lansing, Michigan, USA

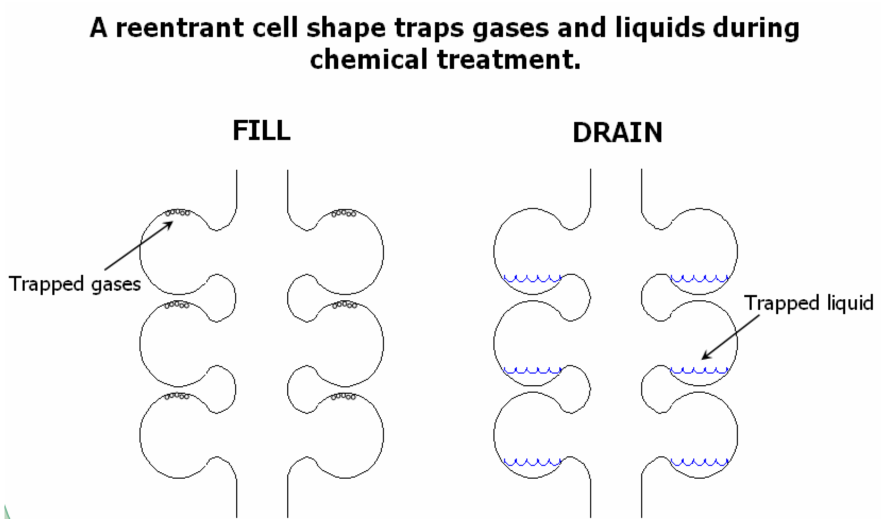
October 17, 2007
13th International Workshop on RF Superconductivity
Peking University
Beijing, China

Thesis Project Overview

GOAL

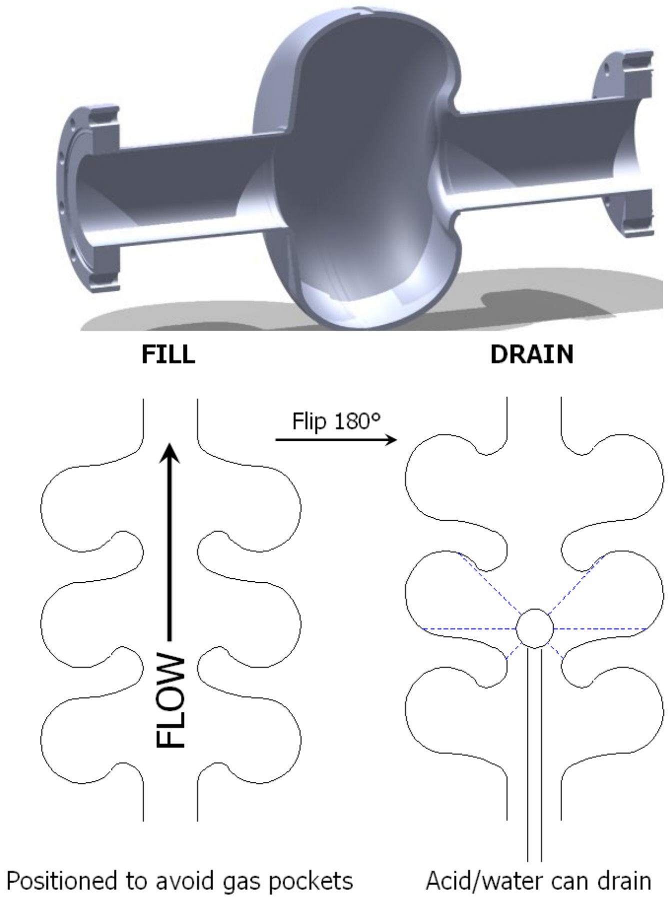
Design cavity with an accelerating gradient ~ 50MV/m for ILC and other high gradient applications. Use Niobium and current technology.

PROBLEM



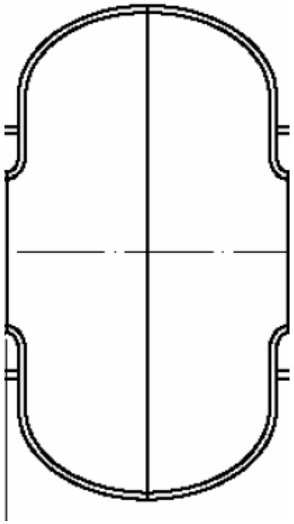
Hydrogen absorption can lead to Q-disease.
A dirty cavity will lead to field emission.

SOLUTION



Three Proposed Cell Shapes for the ILC

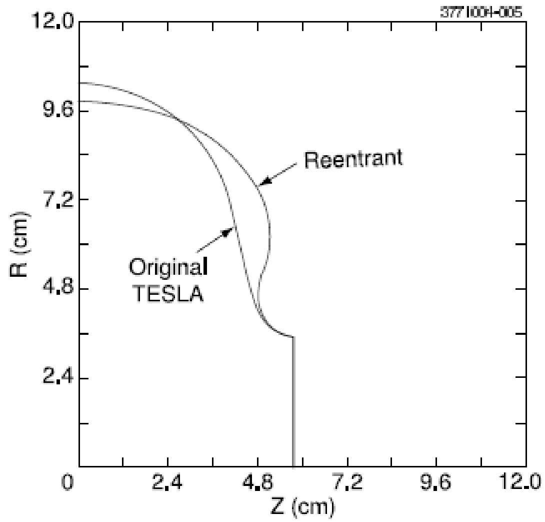
ICHIRO Low-Loss Shape



First developed for JLAB upgrade to
stay within cryogenic capabilities

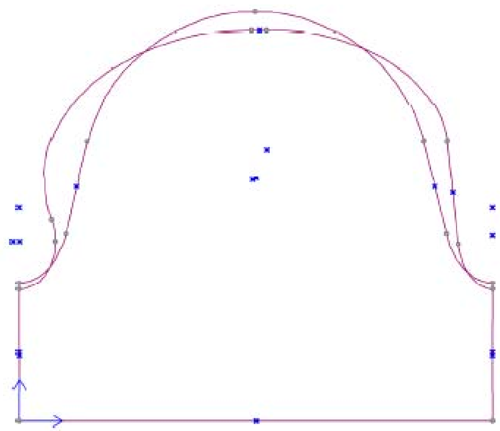
Eacc=51.4 MV/m

Cornell Reentrant Shape



Eacc=52 MV/m

Half-Reentrant Shape

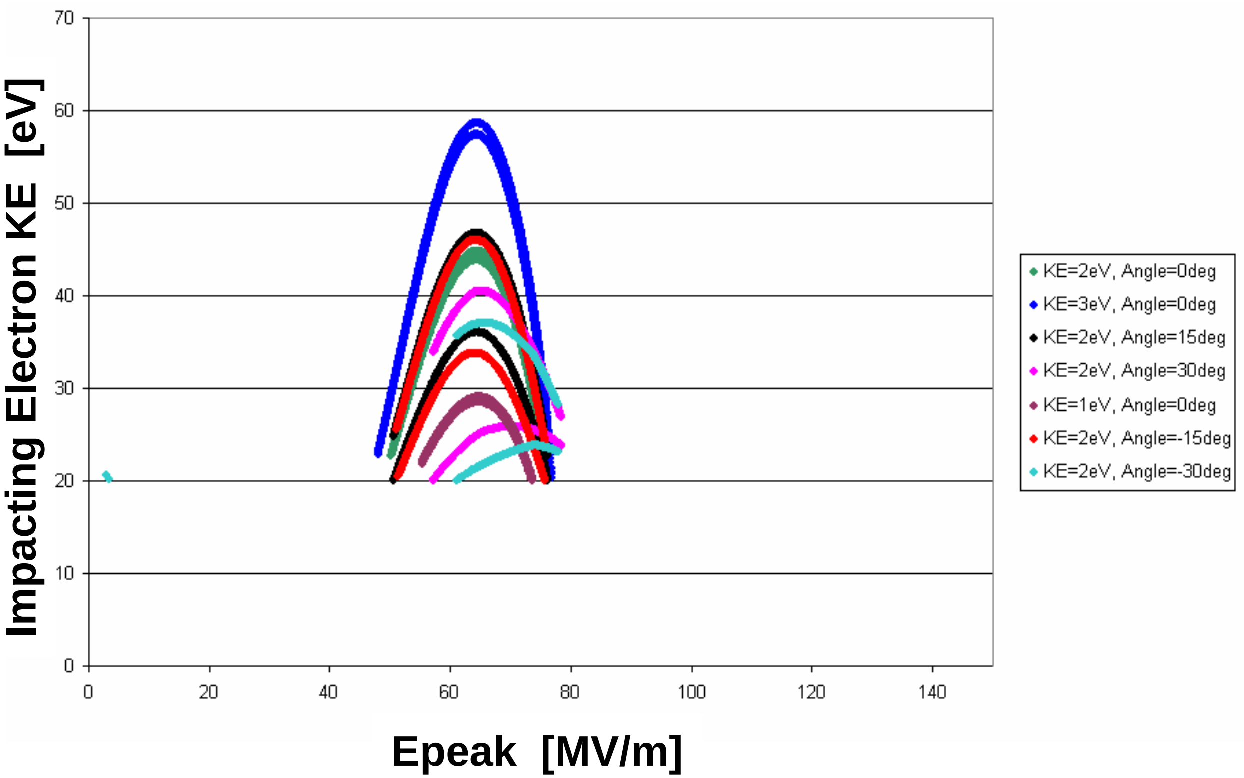


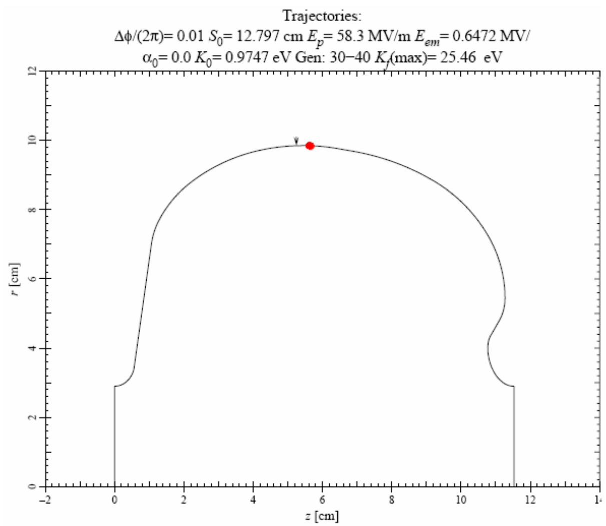
Simulated Eacc=50.8 MV/m.

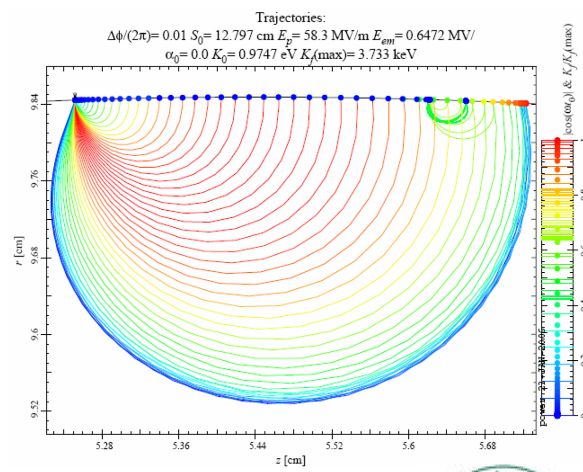
Parameter	Units	TeSLA	Low Loss ICHIRO	Reentrant Cornell	HR with Ellipses
Wall Angle	[degrees]	13.2	0	-	6
kcc	[%]	1.9	1.55	1.57	1.51
Bpk/Eacc	[mT/MV/m]	4.2	3.60	3.55	3.60
Epk/Eacc	[-]	2	2.32	2.26	2.38
R/Q*G	[Ohm-Ohm]	30620	37900	38350	38021
Iris Radius	[mm]	35	30	30	29.7

Relative to TeSLA Geometry
B_{pk} decreases approx. 10%
E_{pk} increases approx. 20%

Multipacting Simulations for Mid-Cell Geometry







MULTIPACTING SIMULATIONS PREDICT:

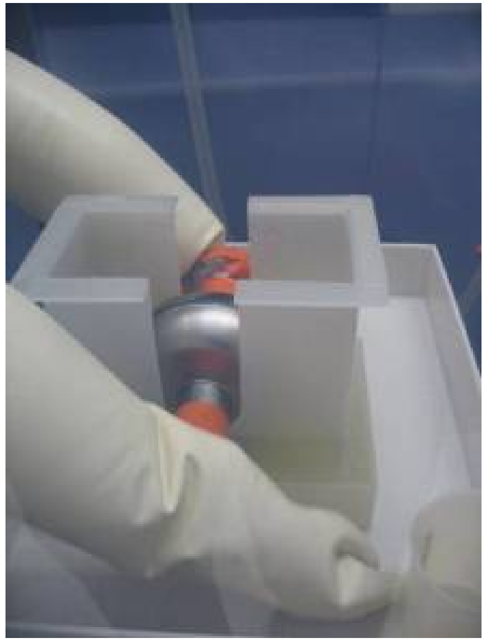
- No hard multipacting barriers.
- One soft multipacting barrier in the range of 20 MV/m < Eacc < 35 MV/m.

Surface Preparation

Glovebox in Chemistry Room

Interior BCP

Exterior BCP



NSCL

HPR

HPR

Department of Physics and Astronomy

Half-Reentrant Cavity on Insert

Test at MSU

Test at MSU

Test at Jefferson Lab

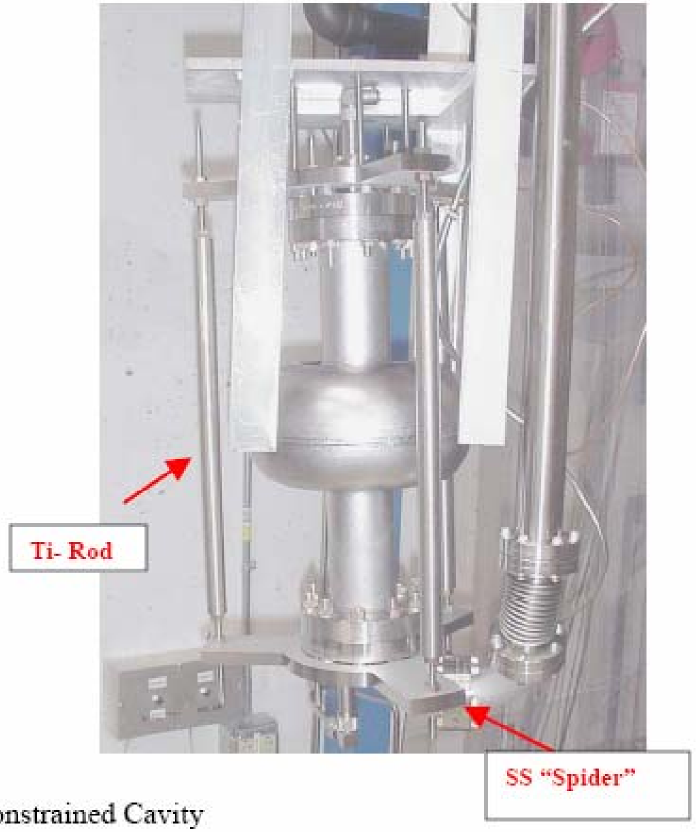
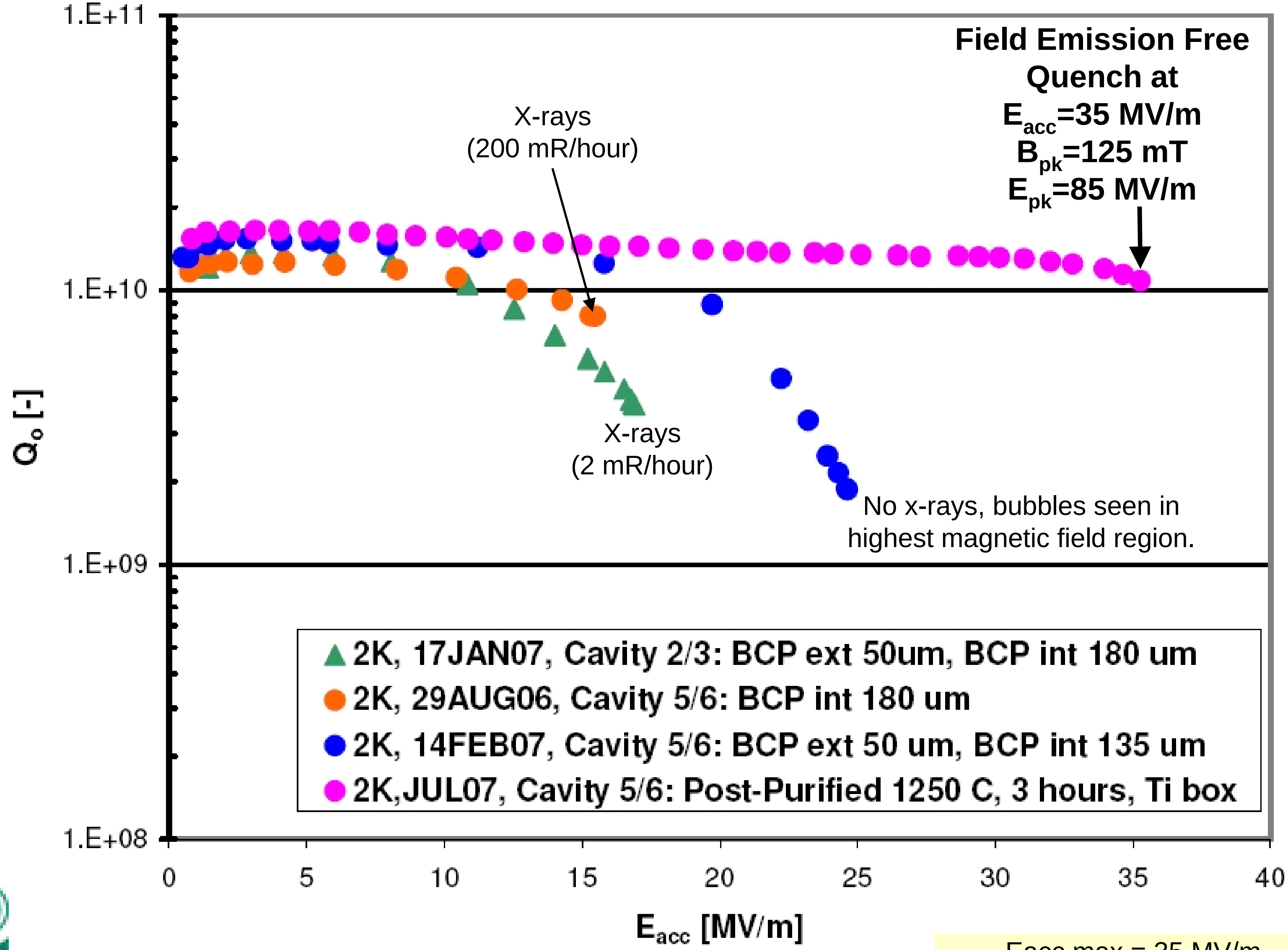


Figure 3: Constrained Cavity

Mirror and video camera allow observation of He bubbles.

Test Results

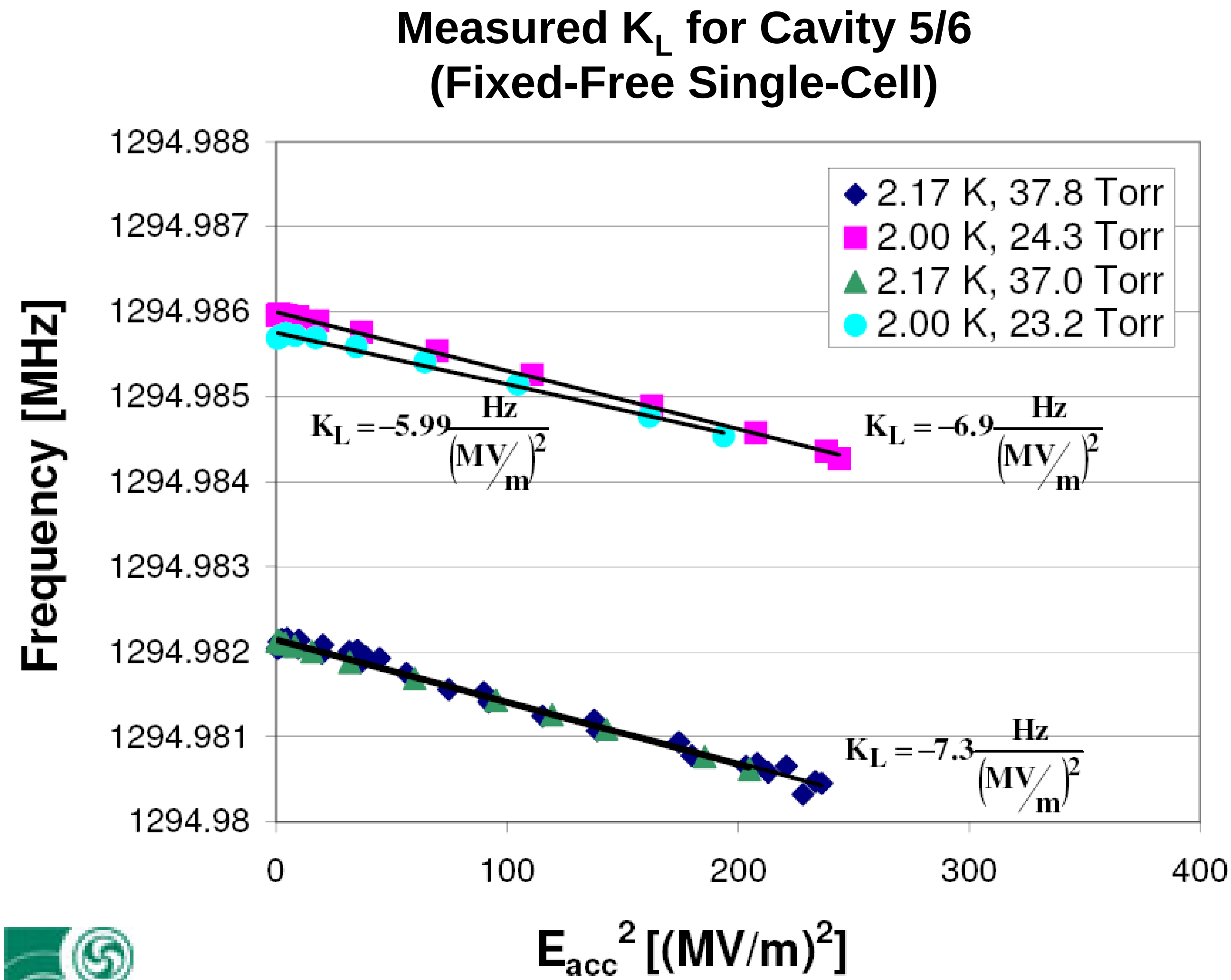
All limited by quench



Epk/Eacc = 2.27
Bpk/Eacc = 3.52 mT/(MV/m)

Eacc,max = 35 MV/m
Bpk max=125 mT
Eacc,max,theoretical = 50 MV/m

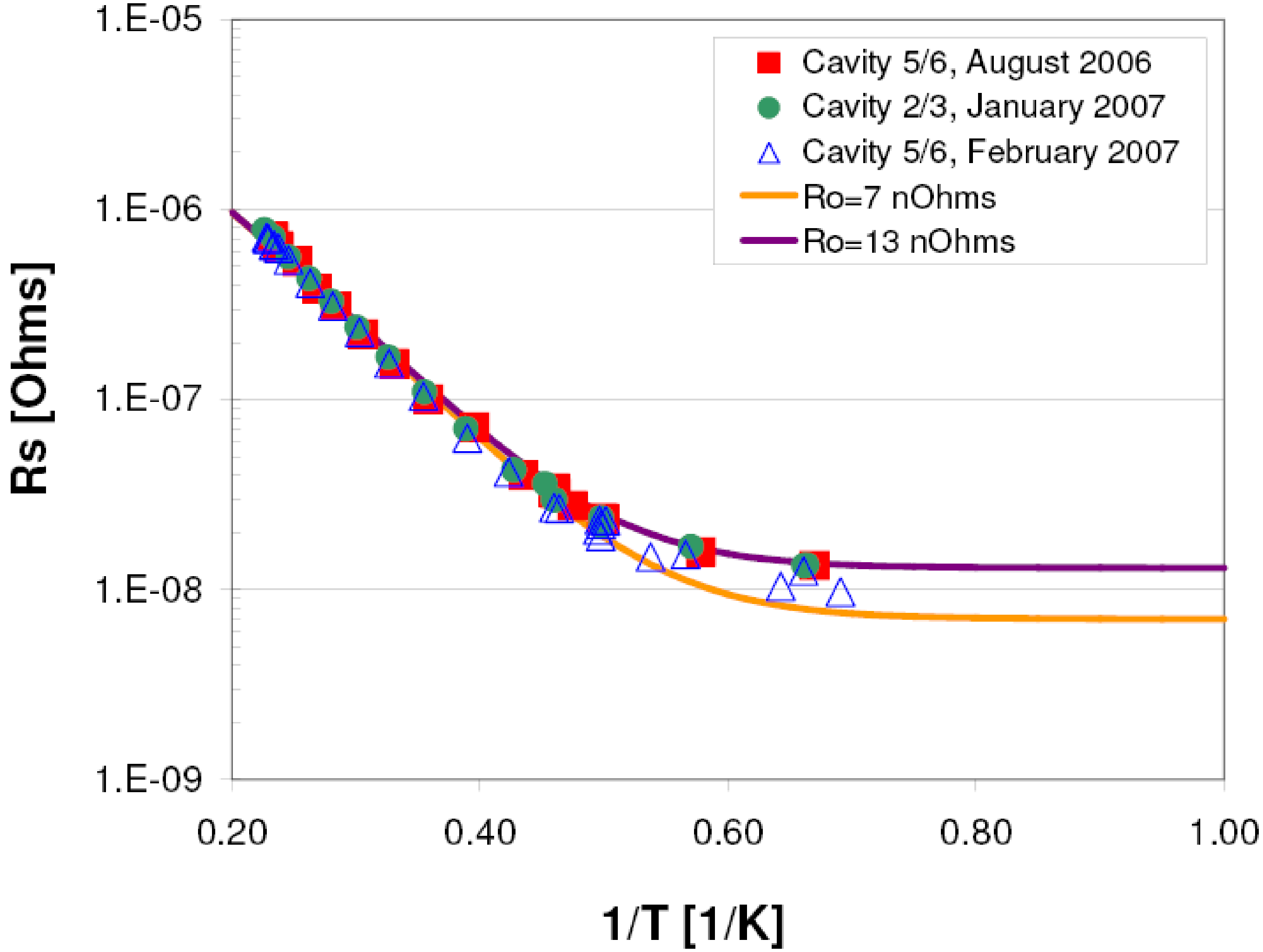
Lorentz Force Detuning Coefficient (K_L)



Predicted K_L for mid-cell geometry with no stiffening rings: -0.5 Hz/(MV/m)^2

Simulations show Half-Reentrant, TeSLA, Low-Loss, and Reentrant mid-cell shapes all have similar K_L.

Surface Resistance



Conclusion of Test Results

- Reached E_{acc}~25 MV/m for second test of cavity 5/6.
- Accelerating gradient reached is consistent with comparable cavities with similar surface treatment (i.e. BCP followed by HPR).
- Cavity 5/6 reached E_{acc}=35 MV/m after post-purification. This is consistent with other BCP/post-purified cavities.
- No multipacting barrier seen, consistent with predictions.
- Next steps would be:
  - Outside etch of post-purified cavity to remove Ti layer.
  - Electropolish followed by bakeout.
- Anticipate higher gradients will be reached.
- Currently no reason to suspect half-reentrant single-cell cavity cannot achieve design gradient of 50 MV/m.

NSCL

Department of Physics and Astronomy

Acknowledgements

John Bierwagen, Steve Bricker, Chris Compton, Terry L. Grimm, Walter Hartung, Matthew Johnson, John Popielarski, Laura Saxton, Richard York

(NSCL, East Lansing, Michigan)

Peter Kneisel (Jefferson Laboratory)

Evgeny Zaplatin (Forschungszentrum Juelich)

Thank You to:

Walter Hartung for thesis guidance.

Rongli Geng for cavity fabrication discussions.

Hasan Padamsee for cavity testing discussions.

Deep Drawing and Electron Beam Welding

Regular two-step process: each half-cell pressed with **75 tons** followed by coining dies pressed with **17 tons**.

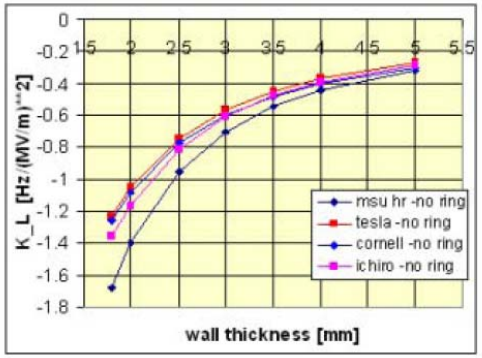
Vent holes were drilled in the reentrant region for both the female and male dies to **allow lubrication to escape** during stamping.

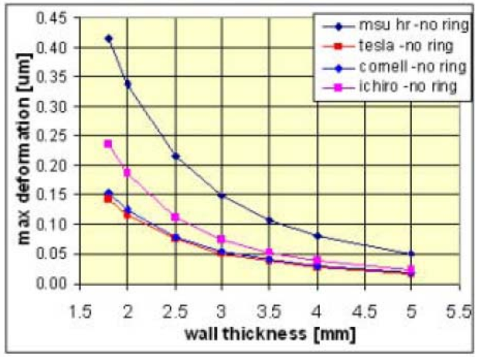
Full penetration equator weld was performed from the outside through **2 mm thick niobium**.

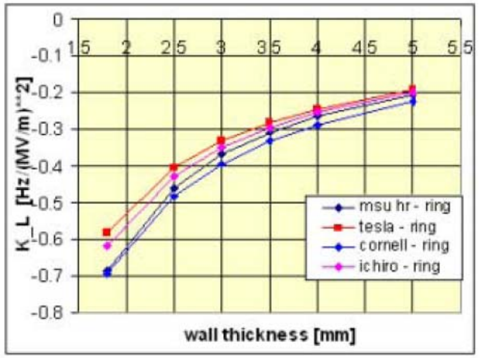
NSCL

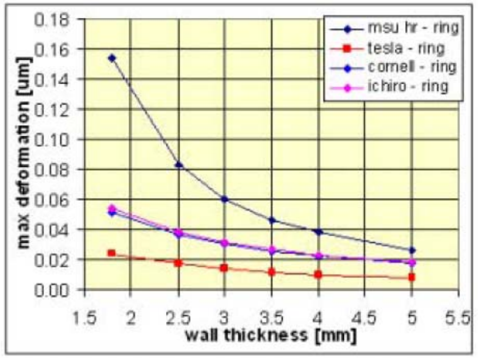
Department of Physics and Astronomy

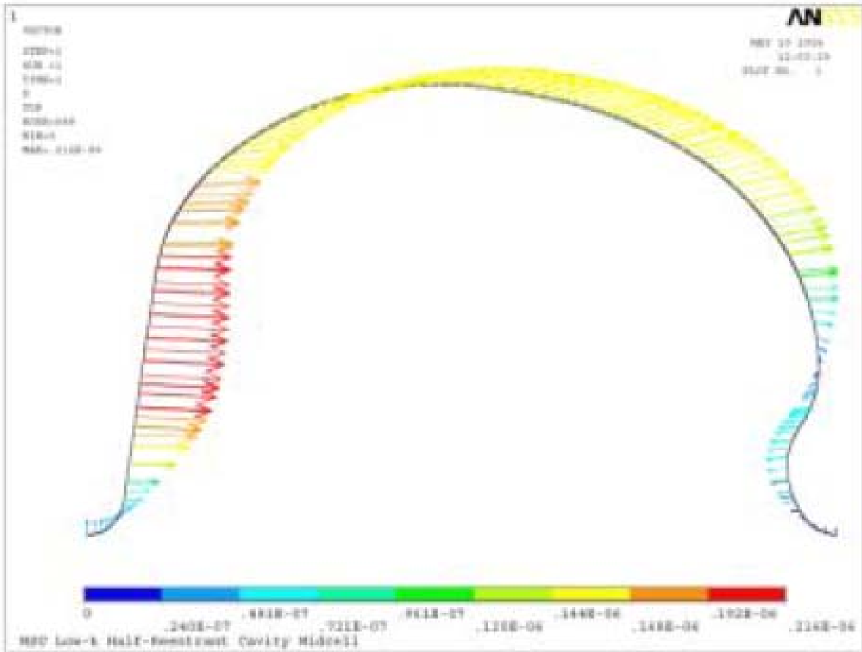
Lorentz Force Detuning Coefficient











HR

Thesis Project Overview

GOAL

Design cavity with an accelerating gradient ~ 50MV/m for ILC and other high gradient applications. Use Niobium and current technology.

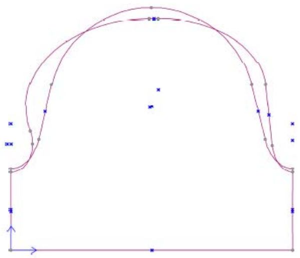
Design
Numerical solution of Maxwell's equations

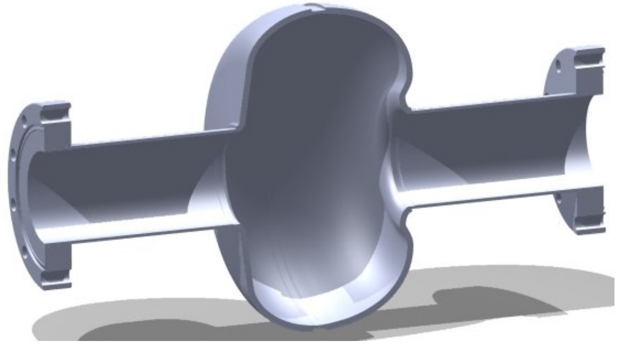
→

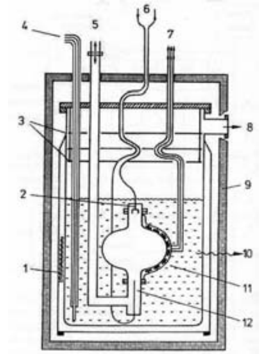
Fabrication
1 Cu prototype, 2 single-cell Nb Cavities

→

Testing
Test single-cell Nb cavity at 4.2K and 2K







To achieve higher gradients, combine reentrant cavity with elliptical cavity shape.
Lower Bpk/Eacc by making cavity half-reentrant at the expense of a higher Epk/Eacc.

$$E_{acc}^{max} = \frac{B_{crit,RF}}{B_{pk}/E_{acc}}$$

← Theoretical Limit ($B_{crit,RF}$)

← Cavity Shape (B_{pk}/E_{acc})

Surface Preparation/Summary

Tested at MSU:

	Cavity 5/6	Cavity 2/3
Surface Preparation	BCP interior 180 um HPR 1x90 minutes	BCP exterior 50 um BCP interior 180 um HPR 1x64 minutes
Test Results (1.5 K)	August 2006 E_{pk}=35.6 MV/m E_{acc}=15.7 MV/m B_{pk}=55.31 mT Q_o=1.4E10 X-ray level = 200 mR/hr	January 2007 E_{pk}=38.2 MV/m E_{acc}=16.8 MV/m B_{pk}=59.2 mT Q_o=4.4E9 X-ray level = 0 mR/hr
Surface Preparation	BCP exterior 50 um BCP interior 135 um HPR 1x65 minutes	
Test Results (1.5 K)	February 2007 E_{pk}=55.8 MV/m E_{acc}=24.6 MV/m B_{pk}=86.6 mT Q_o=2.0E9 X-ray level = 2 mR/hr	

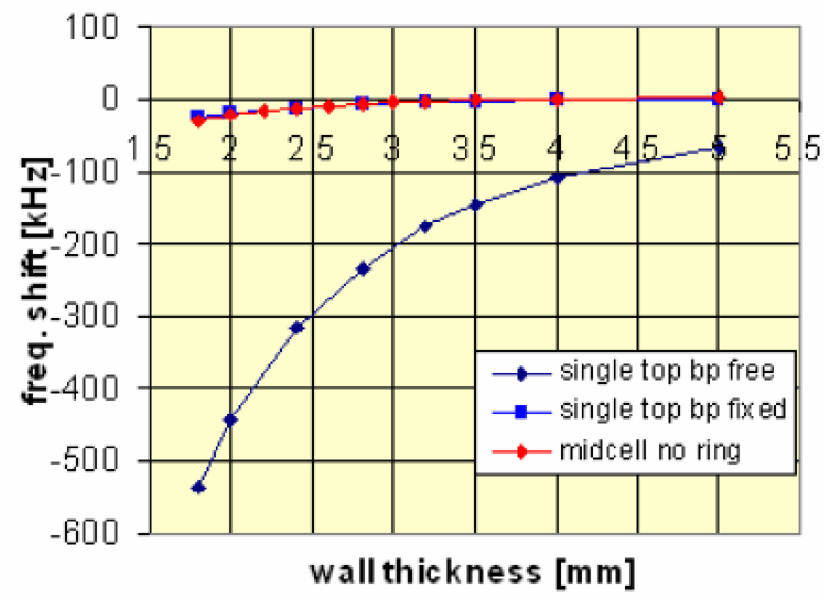
Tested at JLab (Cavity 5/6):

Test #	BCP	Q(2K,E_{max})	$E_{acc,max}$ [MV/m]	B_{peak}[mT]	Comment
1(C)	~ 40 μm	6.2e9	13.8	49	FE, aborted
2 (C)	~ 10 μm	4.2e9	18.9	67	FE, aborted
3 (FH)	~ 10 μm	1e10	35.3	125	Quench,no FE

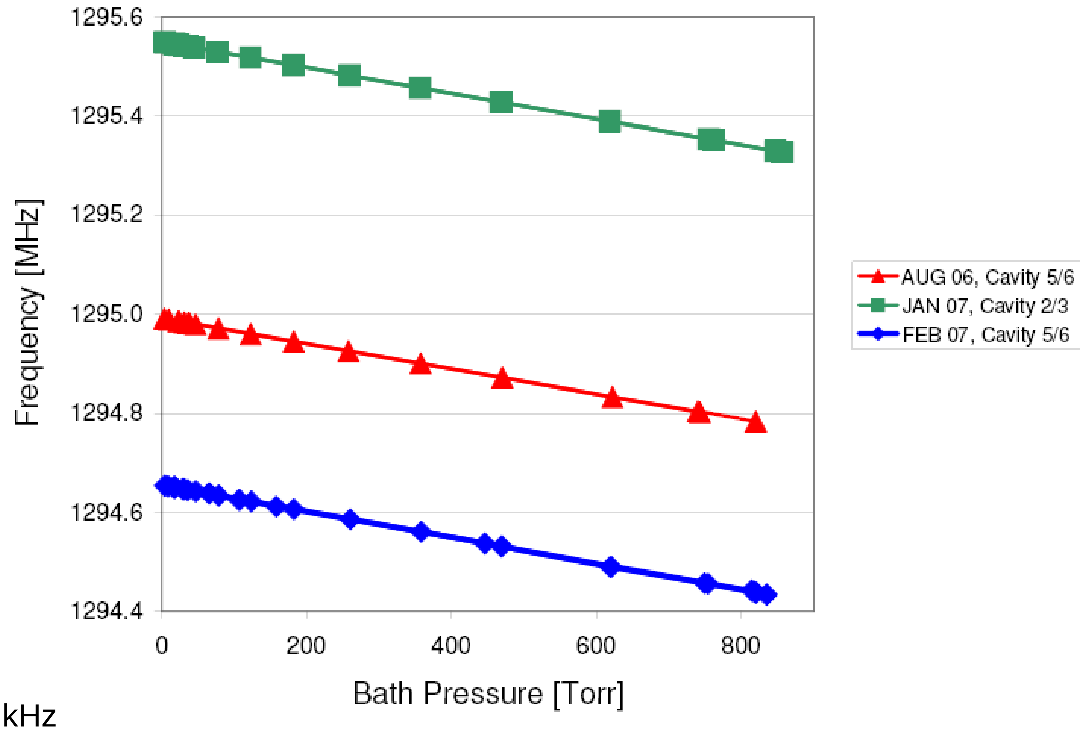
Table 2: Summary of Tests with the Half Re-entrant Cavity (C = constrained, FH = free hanging) **Post-purified at 1250 C for 3 hours in a Titanium box following ultrasonic degreasing**

NSCL

Df/dP



Simulated frequency shift due to cool-down: 2650 kHz



	Material removed after equator weld	df/dP [Hz/Torr]
Cavity 5/6, August 2006	180 um	-254.54
Cavity 2/3, January 2007	230 um	-260.52
Cavity 5/6, February 2007	365 um	-264.53

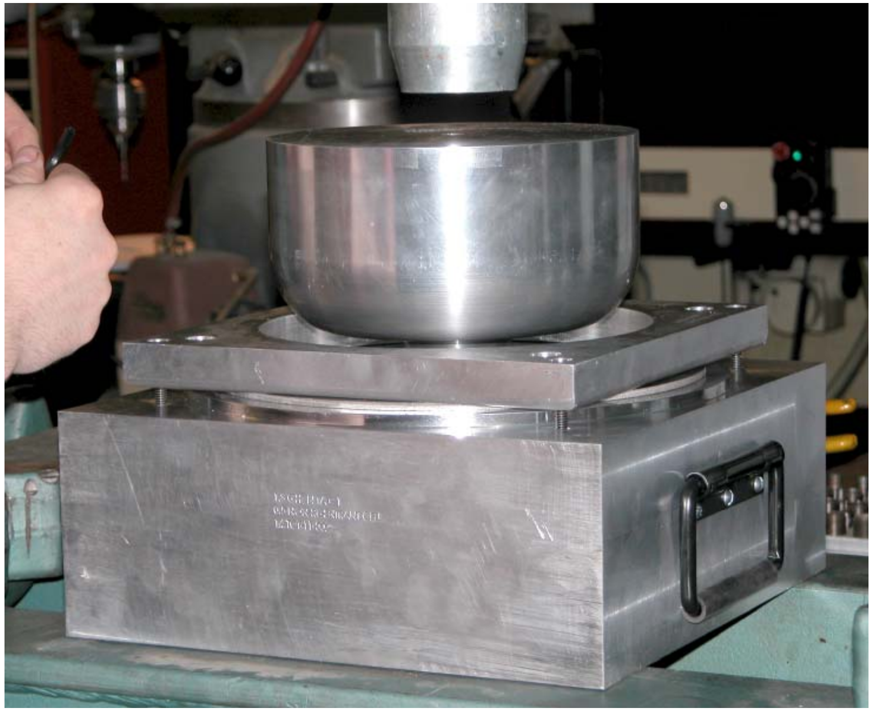
Electron Beam Welding of Iris and Equator

- E-beam welds were completed at Sciaky Corporation in Chicago with a 50 kV welder.
- Full penetration equator weld was performed from the outside through 2 mm thick niobium.
- The equator weld used an oscillation of 1 kHz, maximum spot diameter of 0.005 inches, and gun-to-work distance of 8 inches.
- Tack welds were completed with 18 mA at 18 inches/minute, followed by a seal pass with 38 mA at 18 inches/minute.
- The main e-beam weld was then done for cavity 2/3 with 48mA, 12 inches/minute. The weld did not fully penetrate, so the cavity was rewelded with 55 mA, 12 inches/minute, following the rule of thumb to increase the current by 10%.
- Cavity 5/6 was e-beam welded one time with 51 mA, 12 inches/minute. While the weld for cavity 2 was sufficient, we plan to use 53 mA for the main equator weld for future cavities.

NSCL

Department of Physics and Astronomy

Deep Drawing Cavity Half-Cells



- Vent holes were drilled in the reentrant region for both the female and male dies to allow lubrication to escape during stamping.
- The half-cells were trimmed and interlocking equator and iris joints were machined.

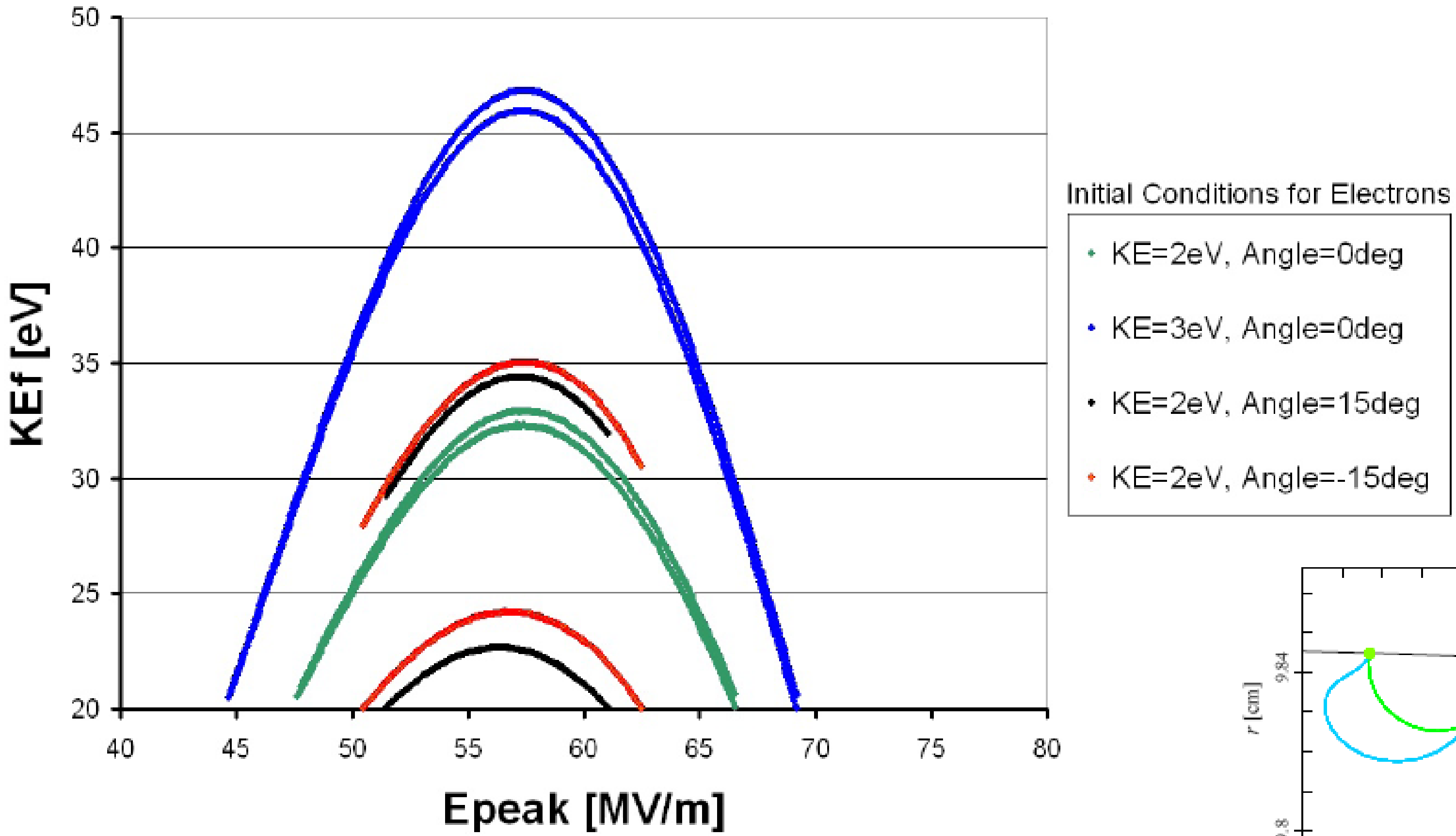
- Regular two-step process with each half-cell pressed with 75 tons followed by coining dies pressed with 17 tons.
- No noticeable tearing of the initial copper test blanks, even with small inner diameter holes.
- Outer edge of the niobium constrained with the proper torque on the hold down bolts.
- No intermediate anneals were performed.

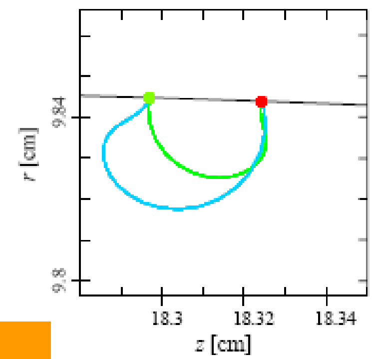
NSCL

Department of Physics and Astronomy

Multipacting Simulations for Single-Cell Geometry

Results

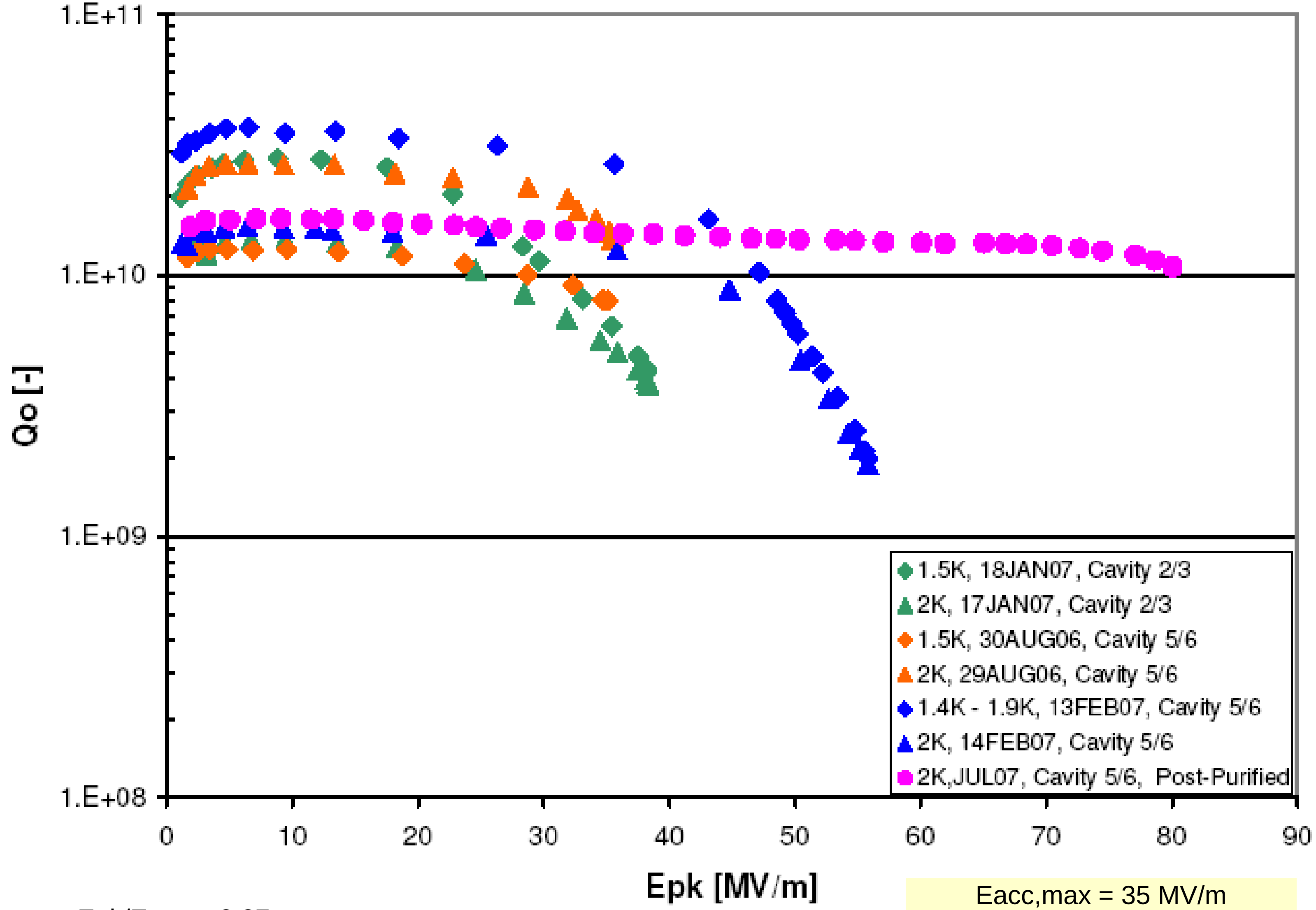




Multipacting simulations predict:

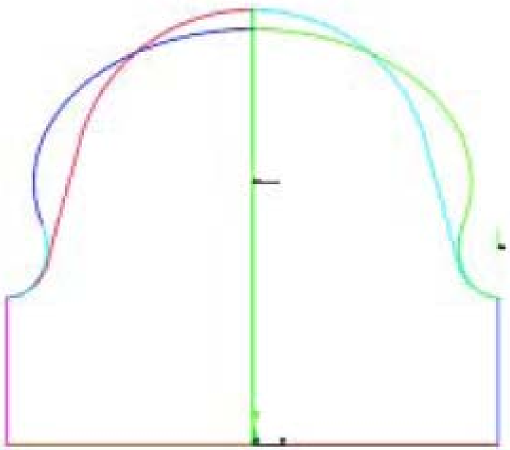
- No hard multipacting barriers.
- One soft multipacting barrier in the range of 45 MV/m < Epeak < 70MV/m.
- First-order two point multipacting.

Test Results

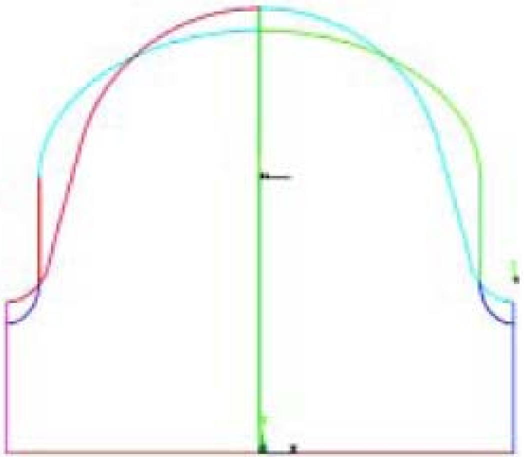


Epk/Eacc = 2.27
Bpk/Eacc = 3.52 mT/(MV/m)

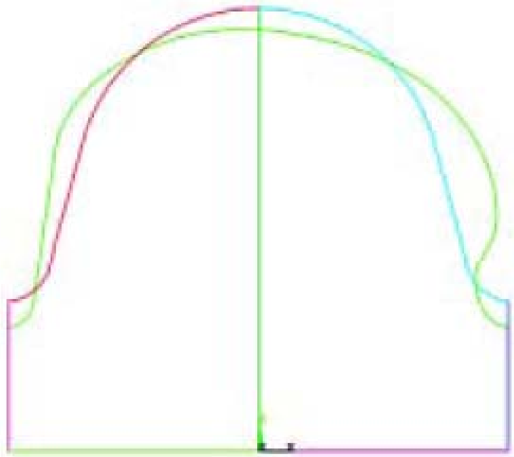
Eacc,max = 35 MV/m
Bpk max=125 mT
Eacc,max,theoretical = 50 MV/m



TeSLA + Cornell



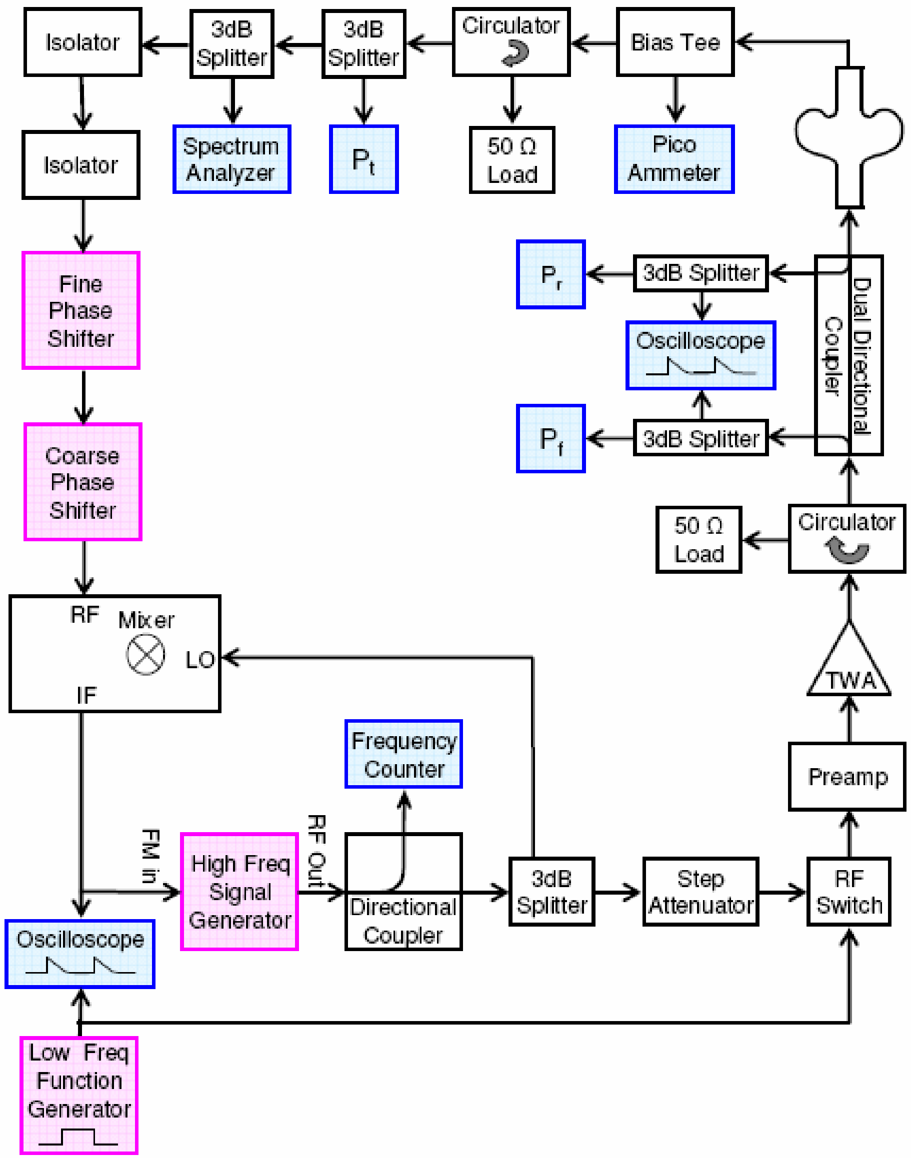
TeSLA + ICHIRO



TeSLA + HR

NSCL

Department of Physics and Astronomy



Isolator
3dB Splitter
3dB Splitter
Circulator
Bias Tee
Isolator
Spectrum Analyzer
P_t
50 Ω Load
Pico Ammeter
Fine Phase Shifter
P_r
3dB Splitter
Oscilloscope
Dual Directional Coupler
P_f
3dB Splitter
Coarse Phase Shifter
50 Ω Load
Circulator
RF
Mixer
LO
IF
TWA
Frequency Counter
Preamp
FM in
High Freq Signal Generator
RF Out
Directional Coupler
3dB Splitter
Step Attenuator
RF Switch
Oscilloscope
Low Freq Function Generator

In test #1 the temperature dependence of the surface resistance was measured between 4.2k and 2K at low power and the data were fitted to the BCS theory, resulting in the following material parameters:

Critical temperature	9.25K	[fixed]
London Penetration depth :	32 nm	[fixed]
Coherence length:	62 nm	[fixed]
Residual resistance:	(8.76 $\pm$ 0.81) nΩ	[fitted]
Mean free path:	(221 $\pm$ 105) nm	[fitted]
Δ/ k T_c :	(1.81 $\pm$ 0.04)	[fitted]

Figure 4 shows the T-dependence of the surface resistance

Coordinate Measurement

- CM done before and after iris weld
- maximum deviation of the fabricated shape from the design shape, before the equator weld, is reduced to 0.35 mm and is within our goal of 0.5 mm.
- change in the cavity shape near the iris of less than 0.076 mm, consistent with iris weld not being full penetration weld
- Thinning from 4 mm to 3.71 mm as well as a sharp transition in the cavity profile near the iris where the coining die was pressed (increase radius of coining die in future to prevent this step)
- A 0.5 mm allowance for weld shrinkage was designed into the equator prep, however actual weld shrinkage ranged from 0.61 mm – 1 mm.