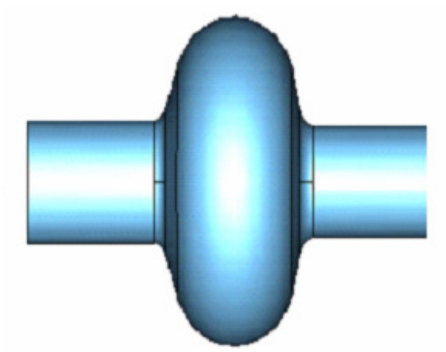
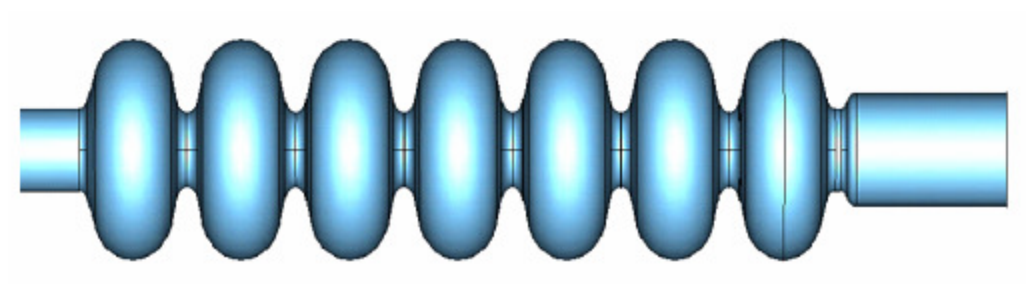
Optimization of Elliptical SRF Cavities where $v<c$

Joel Newbolt

Mentor: Dr. Valery Shemelin





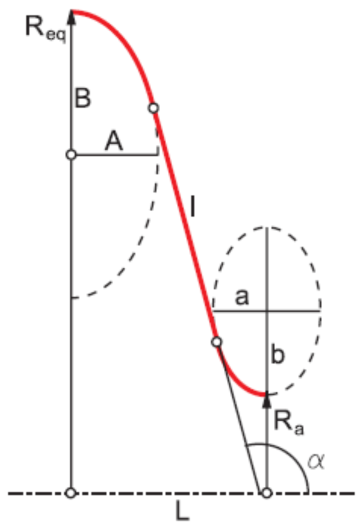
Why $v<c$?

- Acceleration of large subatomic particles
- Accelerator driven systems (ADS)
  - Neutron Spallation
  - Tritium production
  - Nuclear waste transmutation

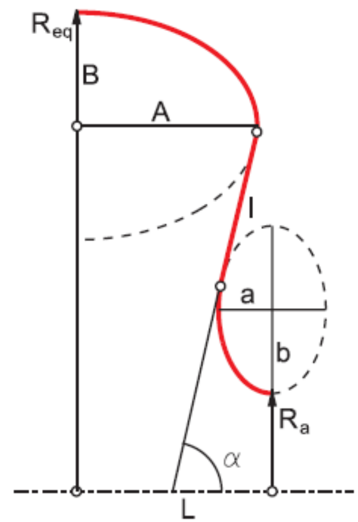
INFN Milano Cavity, $v/c = 0.5$

Elliptical Cell Geometry

Non-reentrant (α>90°)



Reentrant(α<90°)



Geometric Constraints

- Half-Cell Length, L
- Wall Angle, α
- Equatorial Radius, $R\downarrow eq$
- Aperture Radius, $R\downarrow a$

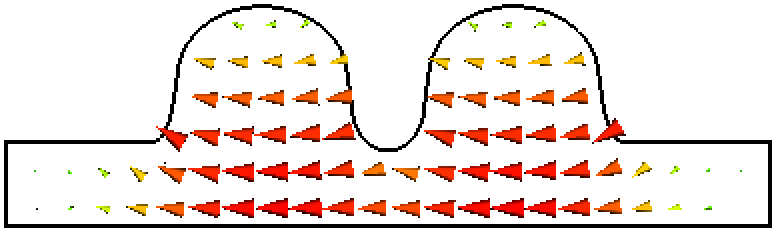
Free Parameters

- Equator Ellipse Axes
  - A and B
- Iris Ellipse Axes
  - a and b

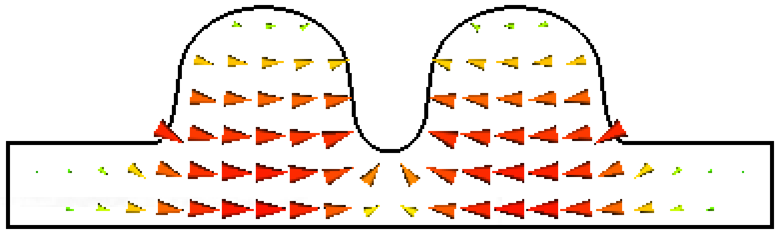
Geometric Constraints

Half-Cell Length, L

Constrained by mode of operation



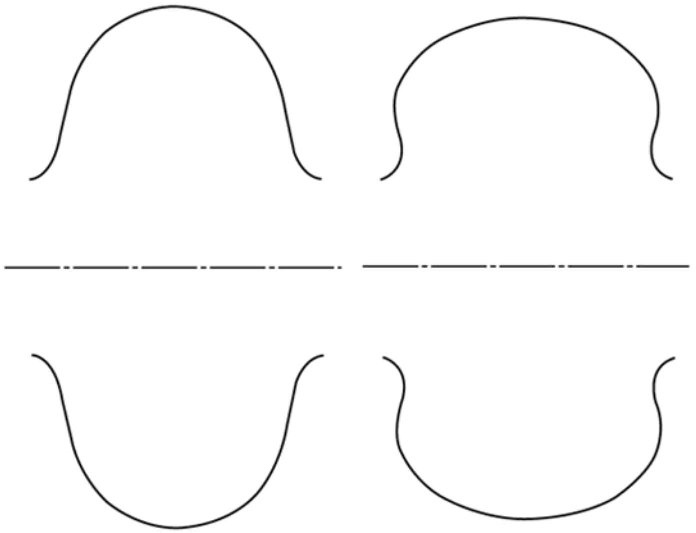
- In-phase mode



- π mode

Wall Angle, α

Constrained by chemical treatment method



Non-reentrant Reentrant

Geometric Constraints (cont.)

Aperture Radius, R_a

- Propagation of higher-order modes (HOMs)

$f_{cutoff} \propto 1/R_a$

  - Removed by resistive loads

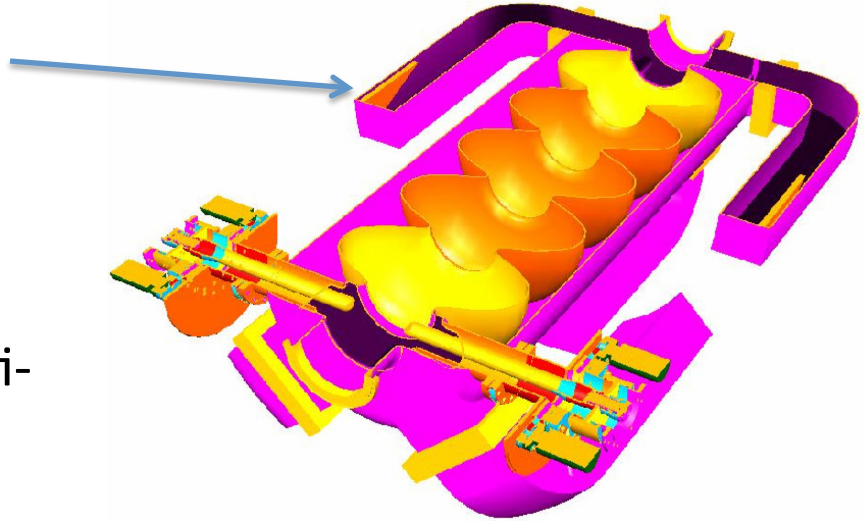
- Power left in cavity by wakefields

$$P \propto 1/R_a^3$$

- Cell-to-cell coupling in multi-cell cavities

Equatorial Radius, R_{eq}

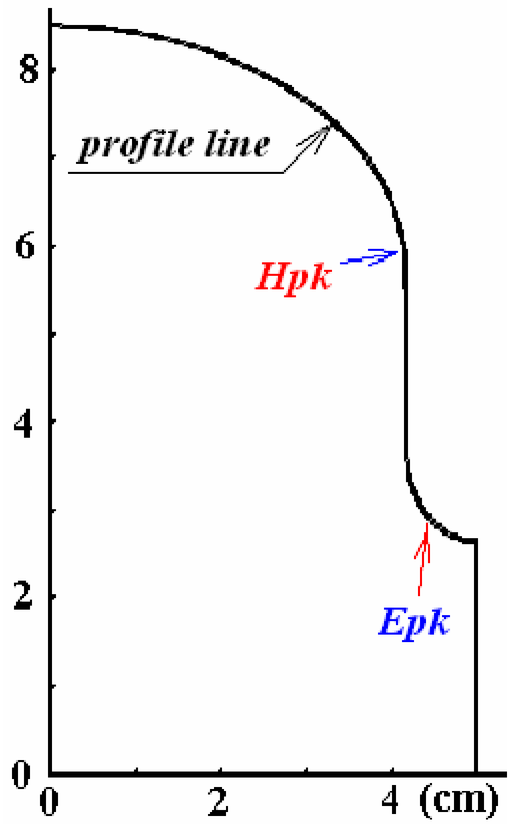
- Tuned to make the frequency of TM_{01} equal to the driving frequency



Peak Fields

Magnetic Quenching

- Superconductor enters a normal conducting state
  - Magnetic field changes too rapidly
  - Magnetic field is too strong
- Causes heating of the material
  - Spreads the region of normal conductivity



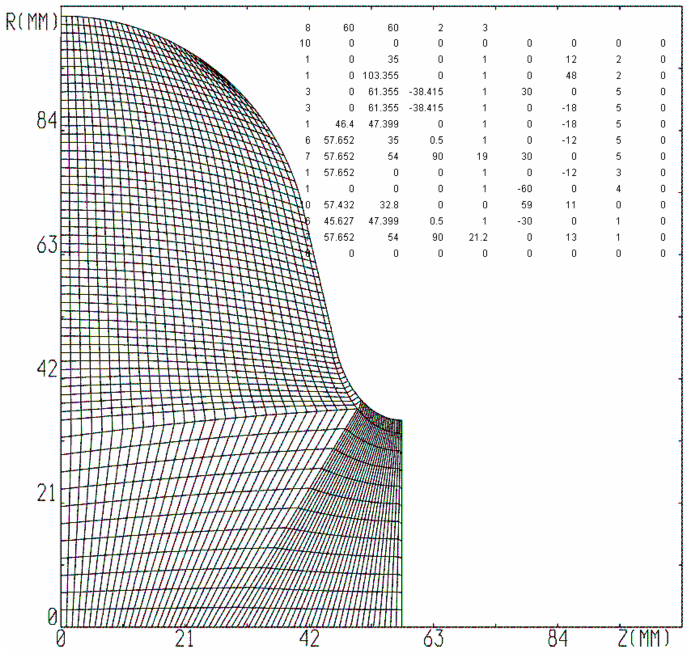
Field Emission

- Electrons are emitted from the superconductor
  - Electric field is too large
- Threshold raised by heat treatment

Numerical Simulation

SUPERLANS

- Simulation for axially symmetric cavities



TunedCell

- Wrapper code for SUPERLANS
  - Adjusts R_{eq} to make the frequency of TM_{01} equal to the driving frequency
  - Creates geometry file for SUPERLANS
  - Linearly varies free parameters

Cavity Optimization

Goal of Optimization

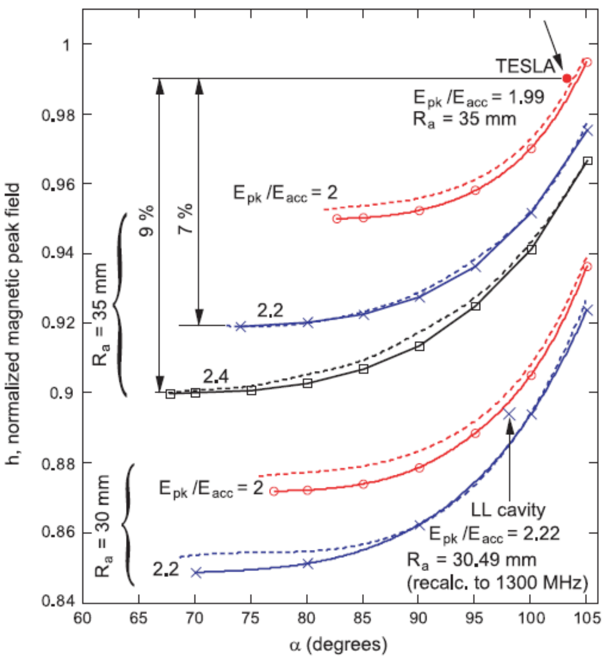
- Minimize B_{pk}/E_{acc} (and equivalently H_{pk}/E_{acc})
- Optimization constraints
  - Minimum wall angle, α
  - Maximum E_{pk}/E_{acc}
  - Minimum radius of curvature of the cell (two times the Niobium sheet thickness ≈ 6 mm)

Cavity Optimizer

- Matlab wrapper code for TunedCell
- Minimizes B_{pk}/E_{acc}
- Enforces geometric and electromagnetic constraints

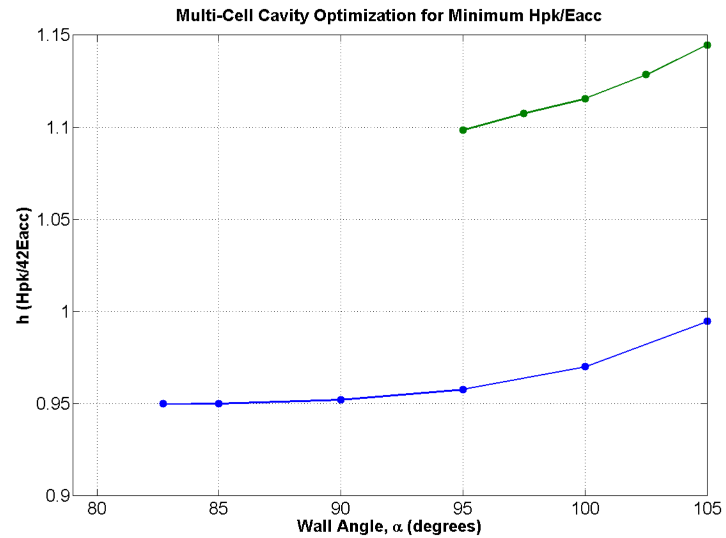
Multi-Cell Cavity Optimization

Optimization by V. Shemelin



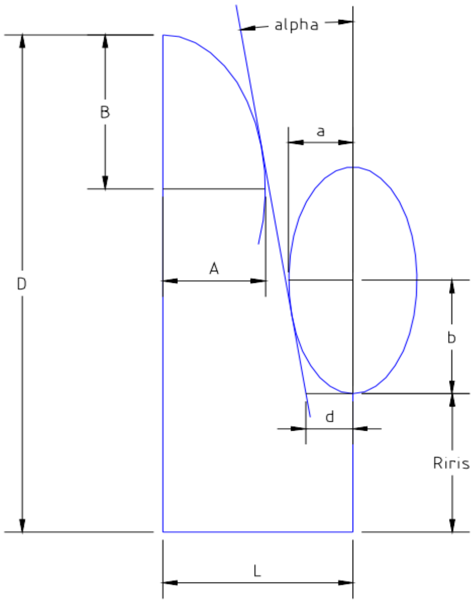
- Reducing wall angle reduces minimum H_{pk}/E_{acc}

Optimization when $\beta = v/c < 1$



- Same trend for $\beta < 1$
- Increasing β increases minimum H_{pk}/E_{acc}

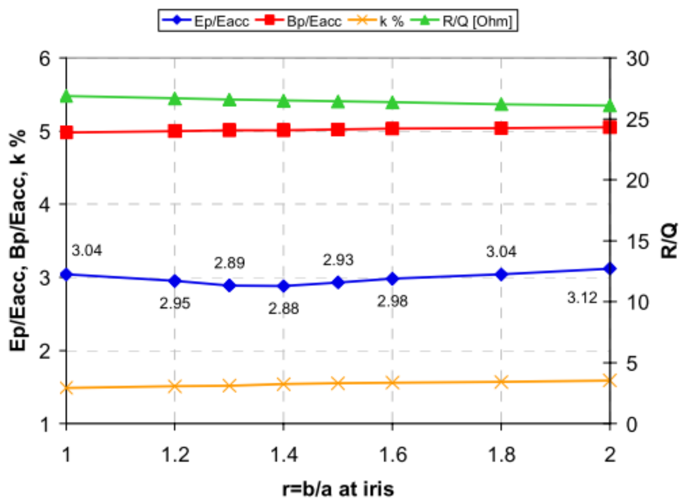
Istituto Nazionale di Fisica Nucleare (INFN)



Free Parameters

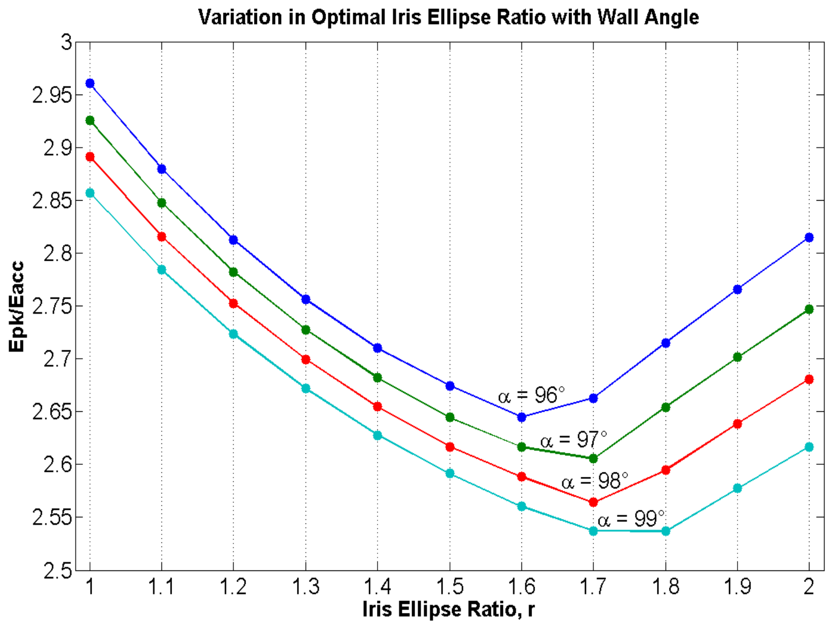
- Equator Ellipse Ratio, $R=B/A$
- Iris Ellipse Ratio, $r=b/a$
- Wall Distance, d
- Wall Angle, $alpha$

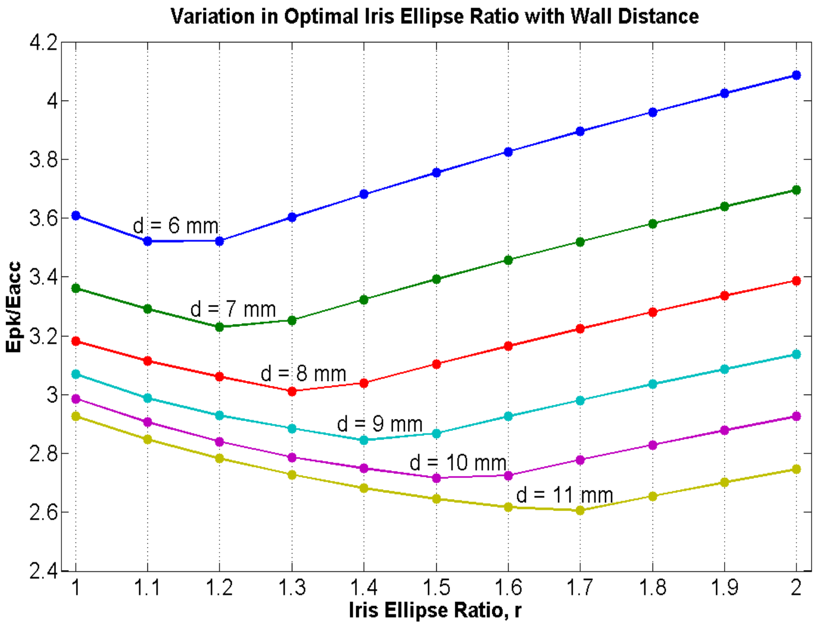
Varying Iris Ellipse Ratio



- Produces a minimum E_{pk}/E_{acc} for a given R, d and $alpha$

INFN Extension





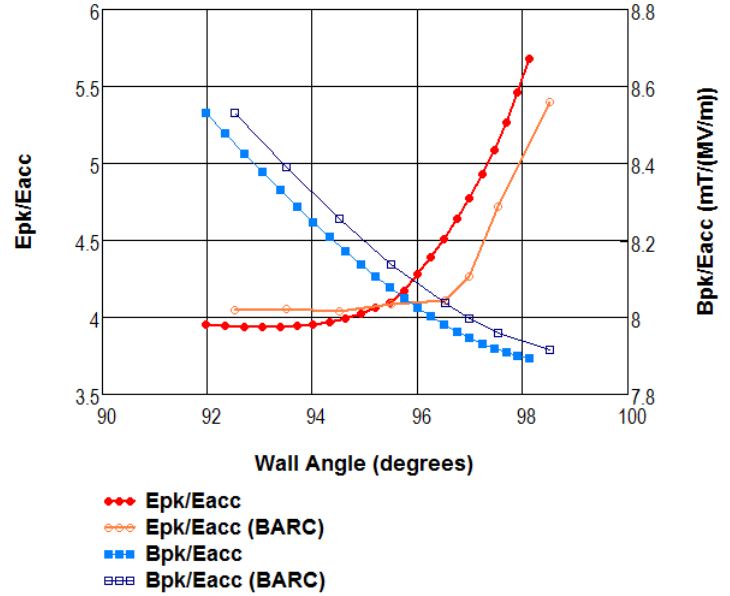
- Increasing wall angle increases optimal iris ellipse ratio
- Increasing wall distance increases optimal iris ellipse ratio

Bhabha Atomic Research Center (BARC)

BARC Optimization

- Single-cell cavity
  - β=0.49
  - A=B=20 mm
  - a/b=0.7
  - $R\downarrow a$=39 mm

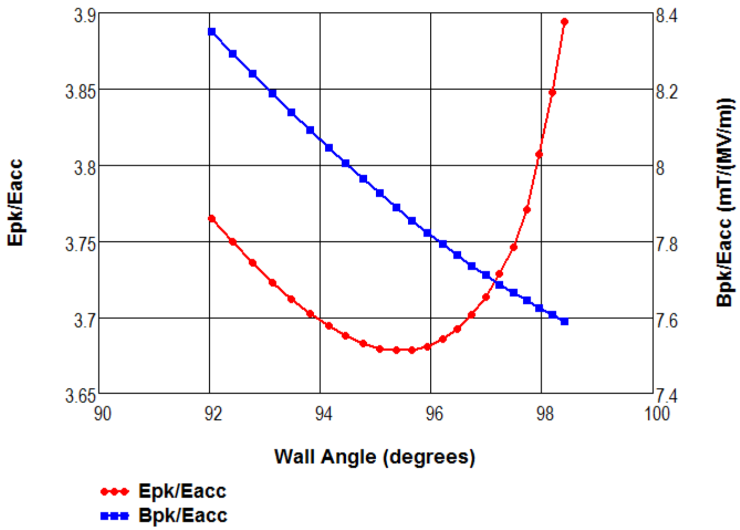
Multi-Cell Boundary Conditions



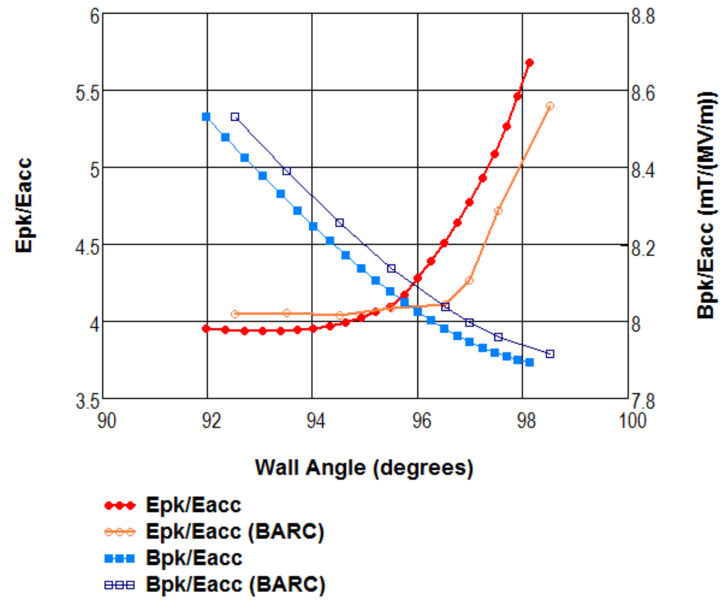
- Qualitatively similar
- Differences attributed to
  - Different levels of free parameter accuracy
  - Different simulation codes (SUPERLANS vs. SUPERFISH)

BARC Verification

Single-Cell Boundary Conditions



Multi-Cell Boundary Conditions



- Clear minimum in E_{pk} / E_{acc}
- Lower values of E_{pk} / E_{acc} and B_{pk} / E_{acc}

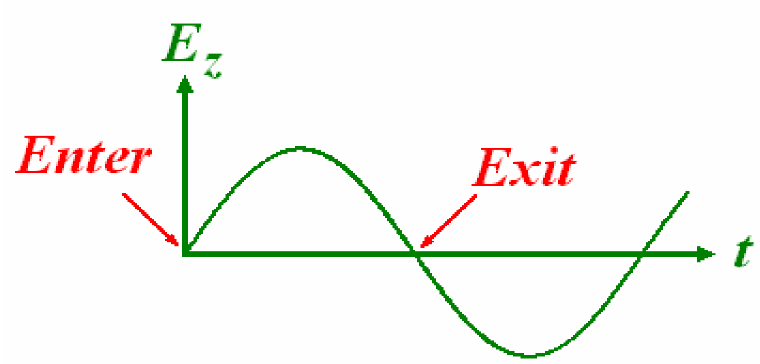
BARC Improvement

	BARC Optimization Results			
Free Parameters	$A=20$ mm	$B=20$ mm	$a/b=0.7$	$\alpha=96.5°$
Electromagnetic Parameters	$E_{pk}/E_{acc}=4.26$		$B_{pk}/E_{acc}=8.02$ mT/(MV/m)	
	Single-Cell Cavity Optimization			
Free Parameters	$A=20.81$ mm	$B=51.3$ mm	$a=10.51$ mm	$b=18.41$ mm
Electromagnetic Parameters	$E_{pk}/E_{acc}=3.50$		$B_{pk}/E_{acc}=8.15$ mT/(MV/m)	

- Optimized under BARC constraints ($\beta=0.49$ and $R_a=39$ mm)
- Result for minimum B_{pk}/E_{acc}

Single-Cell Cavity Length

Half-Cell Length

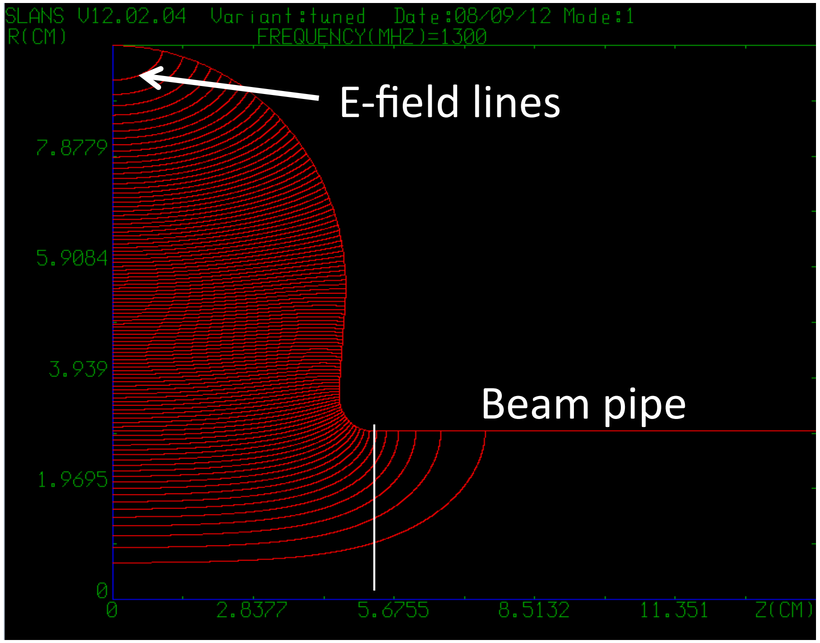


Half-wavelength cell

$L=v/4f$

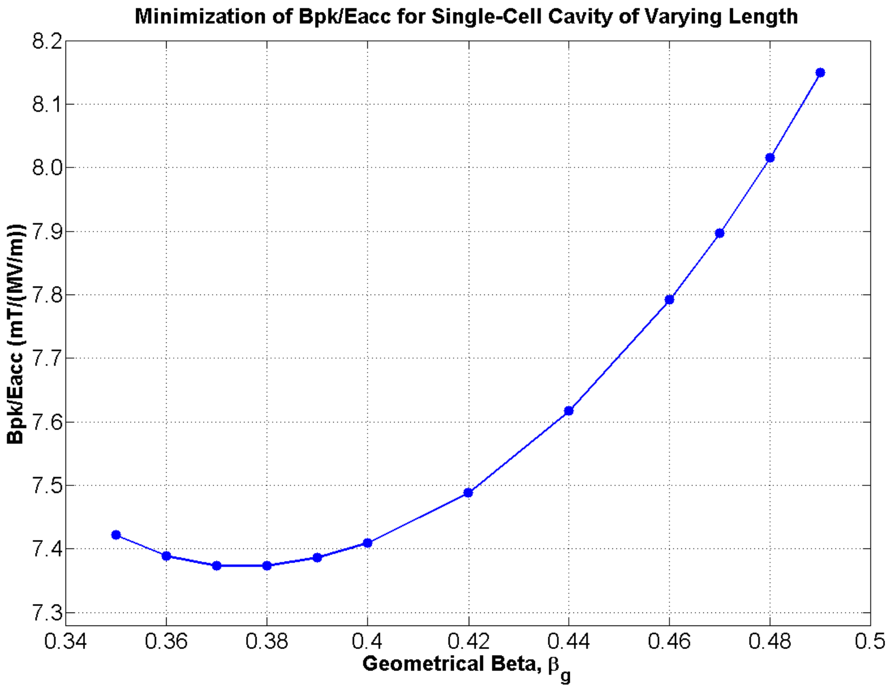
$L=\beta_g c/4f$

Beam Pipe Fields



- Electric field decays exponentially into the beam pipe

Scaled Cavity Length



- Reducing cavity length decreases B_{pk}/E_{acc}
- Reduction from BARC design
  - B_{pk}/E_{acc} by 8%
  - E_{pk}/E_{acc} by 17.8%

Future Work

- Continue optimization of cavities with $\beta<1$
  - Prove reentrant shape is ineffective

- Optimize the shape and length of single-cell cavity with record setting accelerating gradient

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