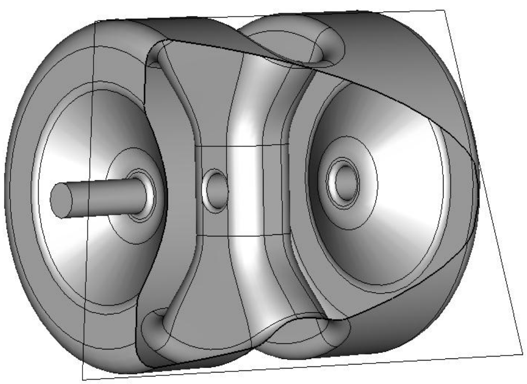
DEVELOPTMENT OF SUPERCONDUCTING SPOKE CAVITIES FOR HIGH-VELOCITY APPLICATIONS AT ODU

Christopher Hopper

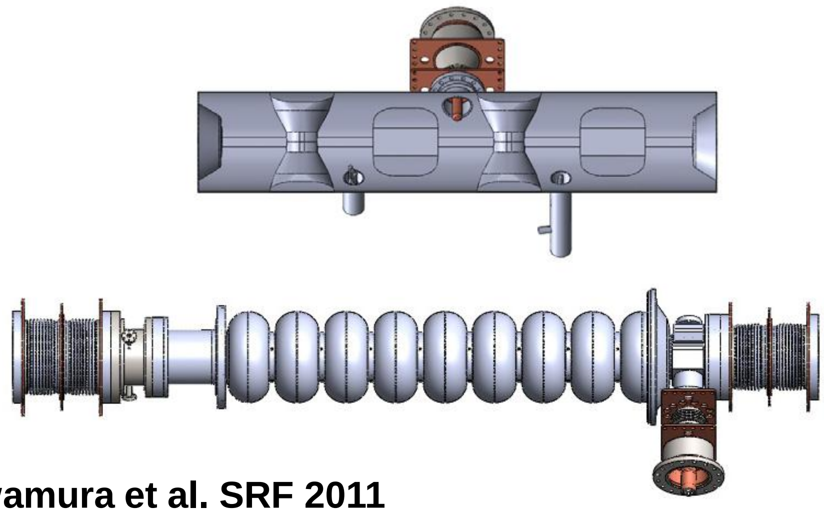
Center for Accelerator Science
Old Dominion University
Department of Physics
and
Thomas Jefferson National Accelerator Facility

Features of Spoke Cavities

- Relative compactness
  - Between 20% - 50% smaller (radially) then a TM cavity of the same frequency
- Strong cell-to-cell coupling
  - Robust with respect to manufacturing inaccuracy
  - No need for field flatness tuning
  - Closest mode well separated
- Low energy content, high shunt impedance
- Couplers located on outer conductor rather than in beamline space



325 MHz, β_0 = 0.82 single-spoke cavity



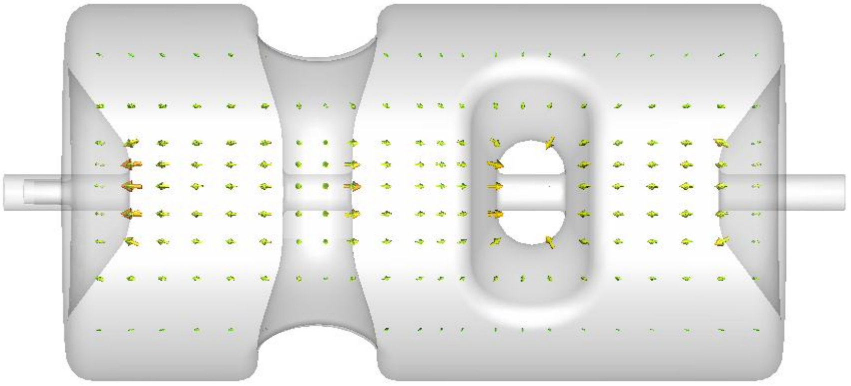
M. Sawamura et al. SRF 2011

Applications

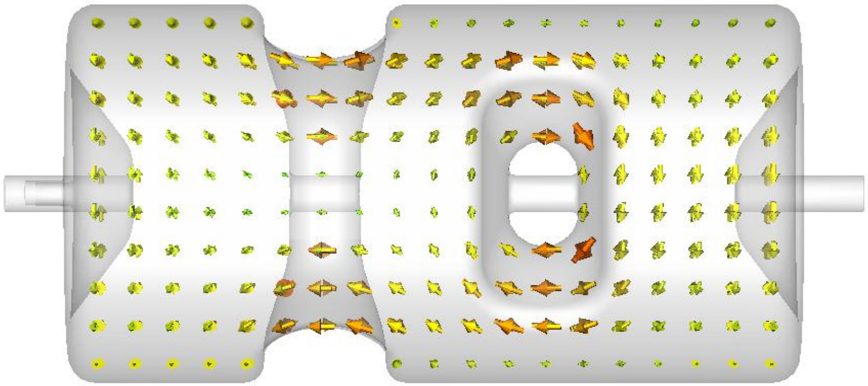
- Compact light sources
  - Lower frequency allows for 4 K operation
  - No sub-atmospheric cryogenic system
- High energy proton/ion linacs
- ERL combined with laser Compton scattering for non-destructive assay system for nuclear materials in spent fuel (JAEA)

Design Goals

Minimizing Peak Surface fields



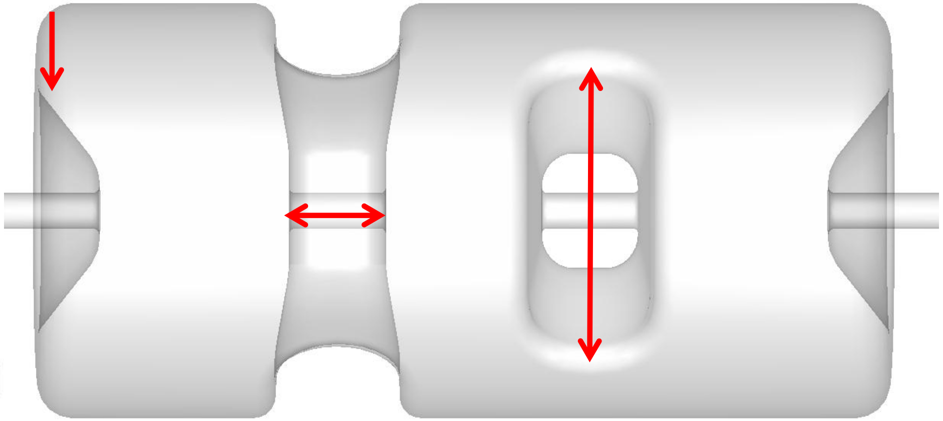
Electric field- Create uniform distribution at aperture region



Magnetic field- Increase surface area of spoke base

Maximize Shunt Impedance

- Spoke base transverse to beam line
- Aperture width closer to base width
- Smaller end cone radius



Cavity Properties

Cavity Parameters	$\beta_0 = 0.82$	$\beta_0 = 1.0$	Units
Frequency of accelerating mode	325	325	MHz
Frequency of nearest mode	333	329	MHz
Cavity diameter	627	640	mm
Iris-to-iris length	949	1148	mm
Cavity length	1149	1328	mm
Reference length	1140	1385	mm
Aperture diameter at spoke	60	60	mm

Cavity Parameters	$\beta_0 = 0.82$	$\beta_0 = 1.0$	Units
Frequency of accelerating mode	352	352	MHz
Frequency of nearest mode	361	357	MHz
Cavity diameter	563	595	mm
Iris-to-iris length	869	1059	mm
Cavity length	1052	1224	mm
Reference length	1044	1277	mm
Aperture diameter at spoke	50	50	mm

Cavity Properties

RF properties	325 MHz, $\beta_0 = 0.82$ *Low Ep,Bp*	325 MHz, $\beta_0 = 1.0$ *High R*	352MHz, $\beta_0 = 0.82$ *Low Ep,Bp*	352 MHz, $\beta_0 = 1.0$ *High R*	Units
Energy gain at β_0	1.140	1.385	1.044	1.277	MV
R/Q	625	744	630	754	Ω
G = QRs	168	195	169	193	Ω
(R/Q)*QRs	1.05×10^5	1.45×10^5	1.07×10^5	1.46×10^5	Ω^2
Ep/Eacc	3.9	4.2	4.1	4.1	-
Bp/Eacc	7.5	8.4	7.4	8.7	mT/(MV/m)
Bp/Ep	1.9	2.0	1.8	2.12	mT/(MV/m)
Energy Content	0.45	0.56	0.35	0.43	J
Power Dissipation*	0.37*	0.43*	0.33**	0.36**	W

At Eacc = 1 MV/m and reference length $(3/2)*\beta_0\lambda$
*Rs = 68 nΩ
**Rs = 73 nΩ

Comparison to TM Cavity

Cavity Parameters	352 MHz, $\beta_0 = 1.0$ *Two-spoke*	352 MHz, $\beta_0 = 1.0$ *3-cell Elliptical*	Units
Frequency of accelerating mode	352	352	MHz
Frequency of nearest mode	357	350.7*, 351.3*	MHz
Cavity diameter	579	724	mm
Iris-to-iris length	1057	1244	mm
Cavity length	1237	1444	mm
Reference length	1277	1277	mm
Aperture diameter at spoke	50	100	mm

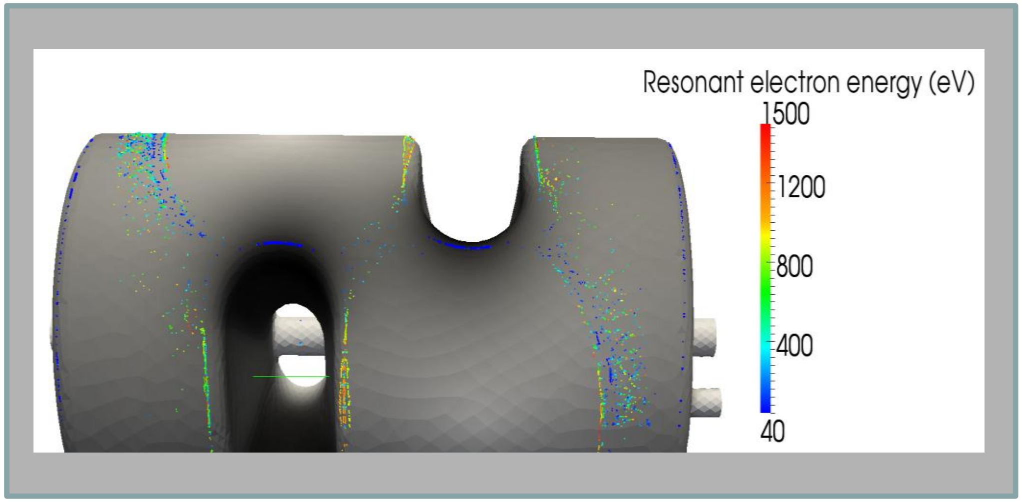
*Lower order modes

RF properties	352 MHz, $\beta_0 = 1.0$ *Two-spoke*	352 MHz, $\beta_0 = 1.0$ *3-cell Elliptical*	Units
Energy gain at β_0	1.277	1.277	MV
R/Q	742	501	Ω
G = QRs	191	268	Ω
(R/Q)*QRs	1.42×10^5	1.34×10^5	Ω^2
Ep/Eacc	4.2	3.5	-
Bp/Eacc	7.0	4.7	mT/(MV/m)
Bp/Ep	1.7	1.34	mT/(MV/m)
Energy Content	1	1.47	J
Power Dissipation*	0.37*	0.39*	W

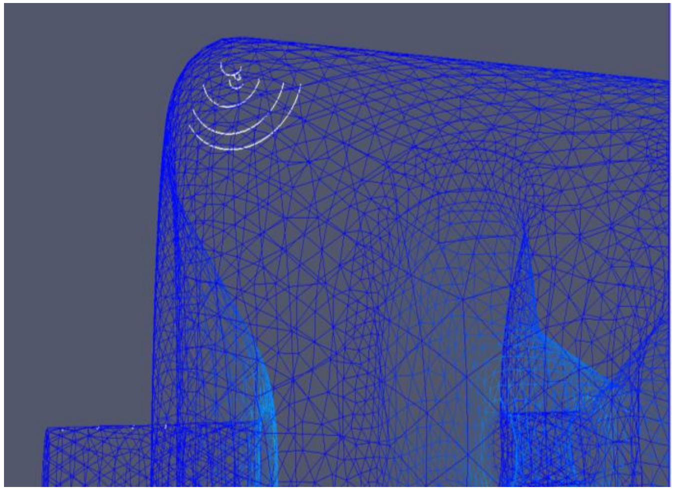
At Eacc = 1 MV/m and reference length $(3/2)*\beta_0\lambda$

*Rs = 73 nΩ

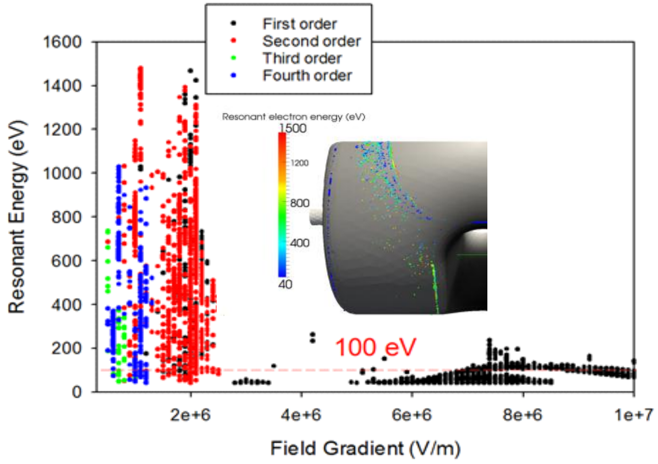
Multipacting

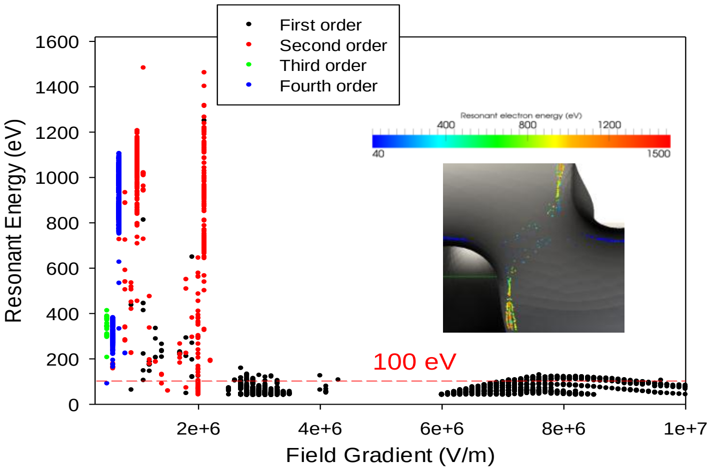


Multipacting sites, 325 MHz, β_0 = 0.82 double-spoke cavity



Two-point, first order multipacting





Jefferson Lab

Simulations done with TRACK3P in the SLAC ACE3P code suite

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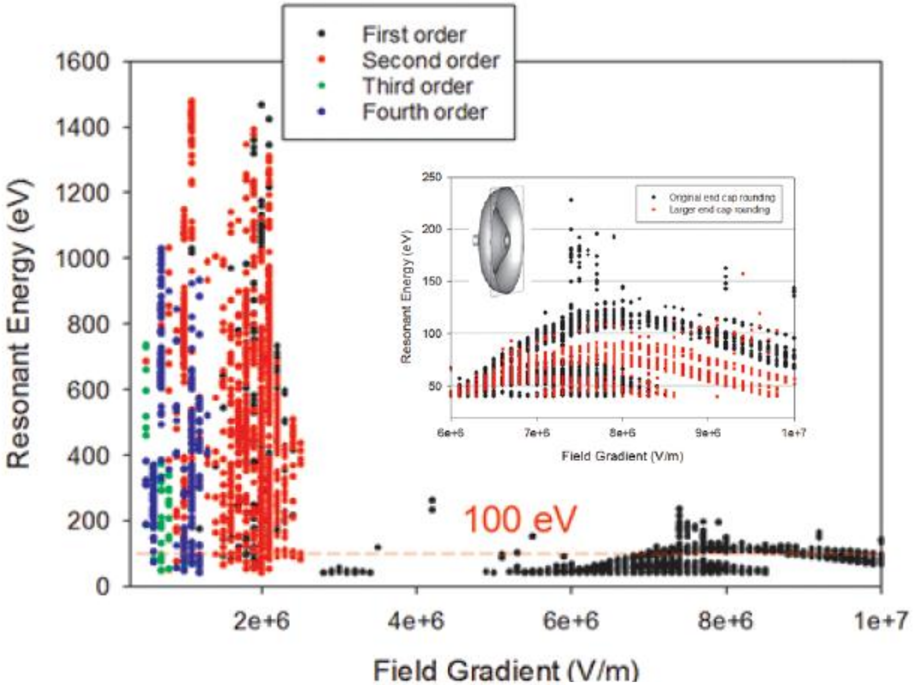
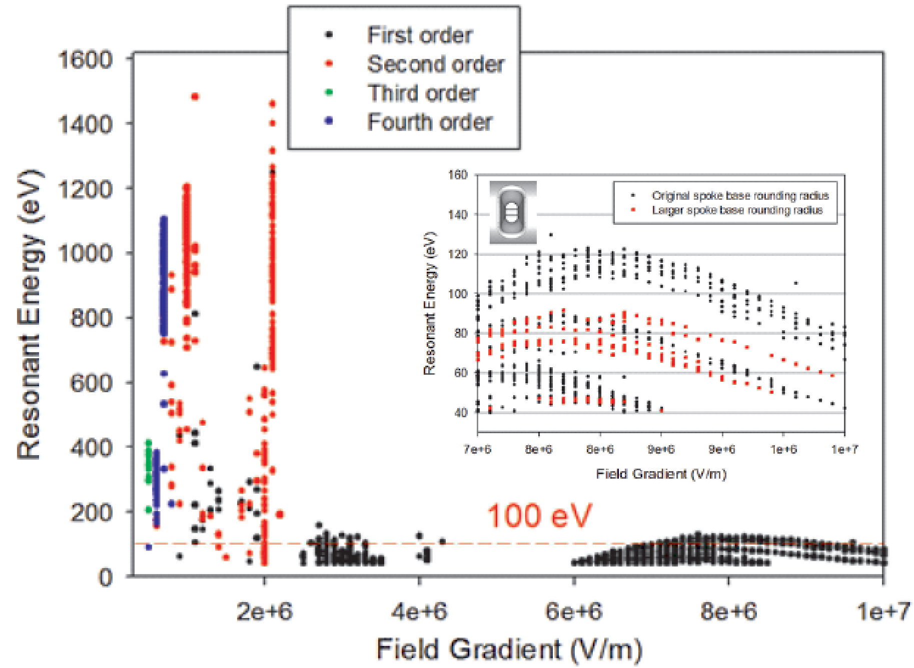
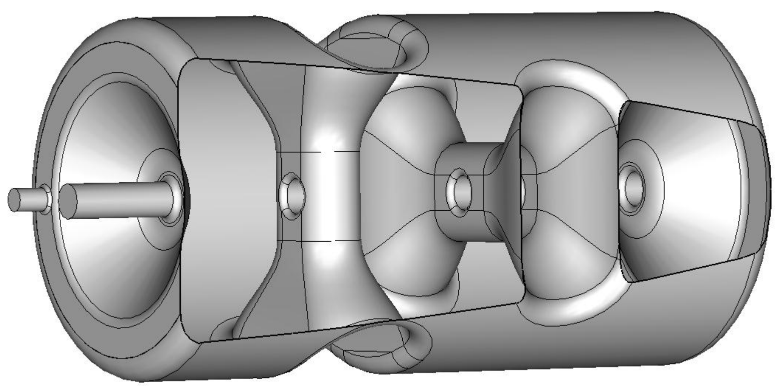
Multipacting



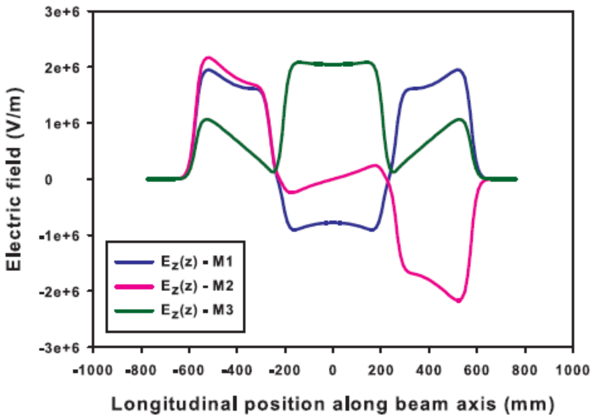




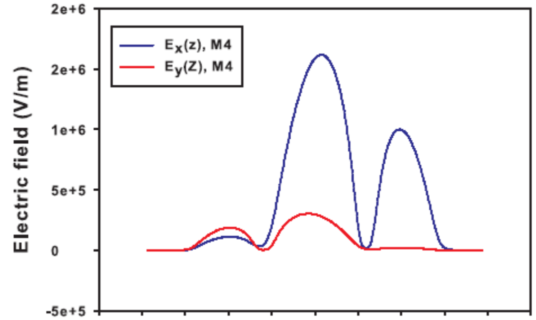
C. S. Hopper and J.R. Delayen, LINAC2012, MOPB056

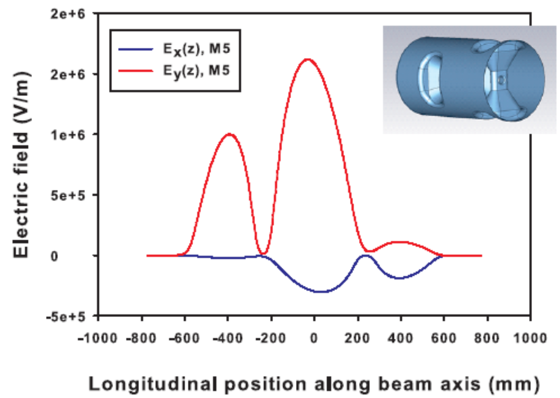
Higher Order Modes

Accelerating modes

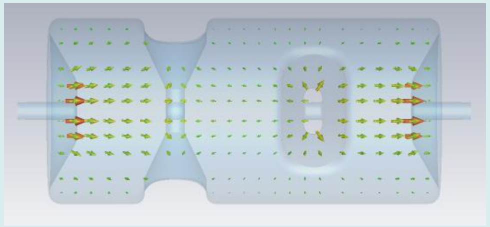


Deflecting (degenerate) modes

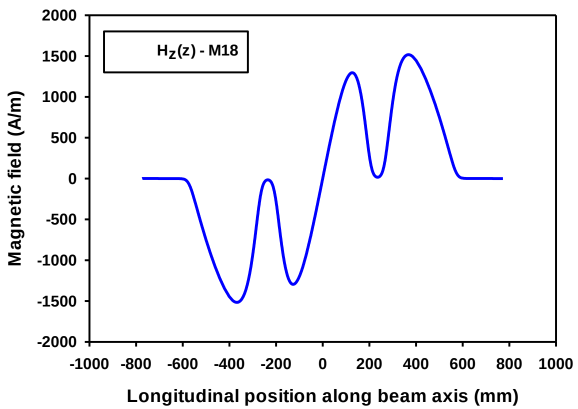




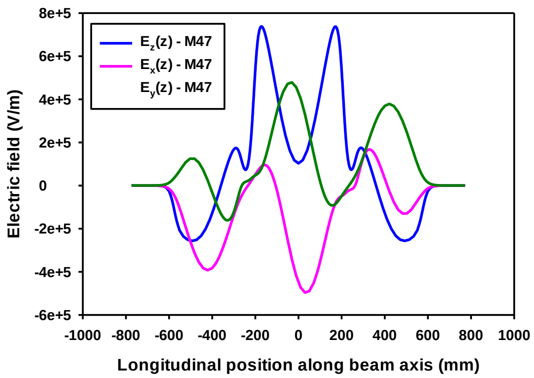
Examples of modes for the 325 MHz cavity, β =1



TE-type modes



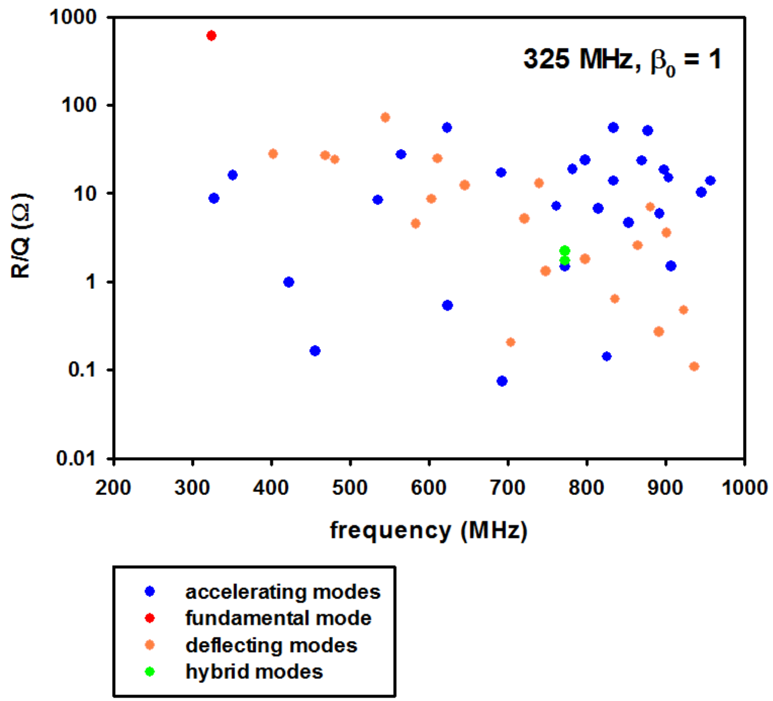
Hybrid modes

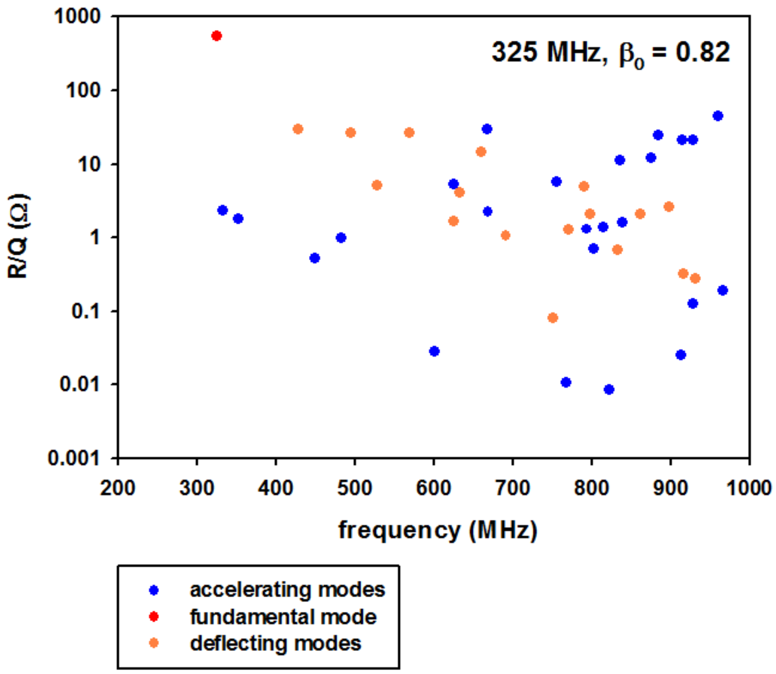


R/Q Values of HOMs

(R/Q) values for particles at design velocities

$\beta_0 = 1$ and $\beta_0 = 0.82$ for the 325 MHz two-spoke cavity



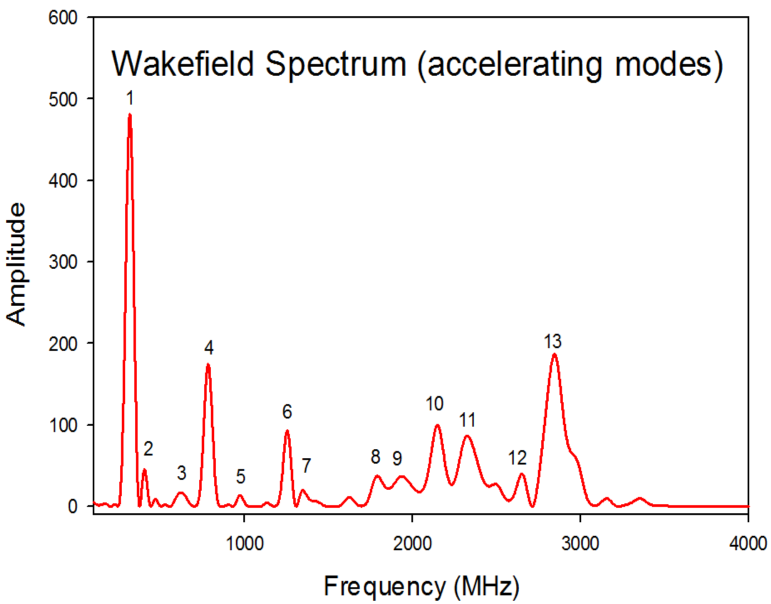


C. S. Hopper, R.G. Olave, J.R. Delayen, IPAC2012, WEPPC103

HOMs have (R/Q)s significantly smaller than the fundamental mode

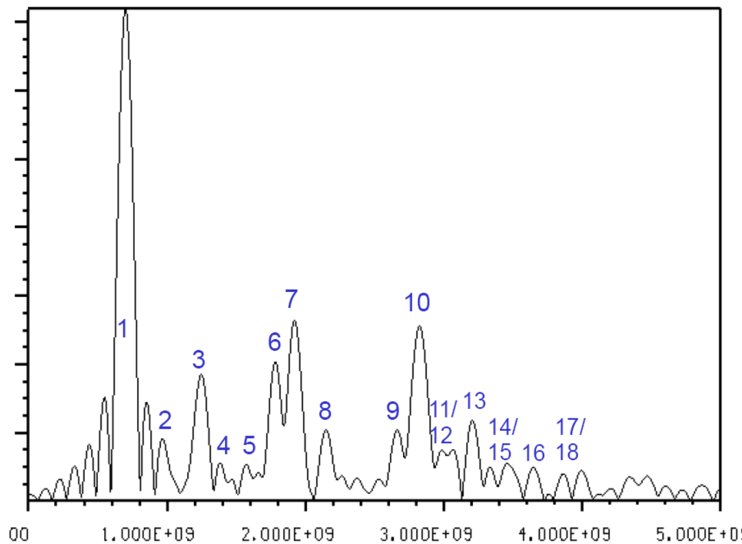
Excitation of Modes by a Single Bunch

Single Gaussian bunch, on-axis, σ = 1 cm
(bunch couples only to accelerating modes)



1: 325 MHz
2: 400 MHz
3: 619 MHz
4: 776 MHz
5: 978 MHz
6: 1246 MHz
7: 1351 MHz
8: 1790 MHz
9: 1936 MHz
10: 2148 MHz
11: 2326 MHz
12: 2676 MHz
13: 2846 MHz

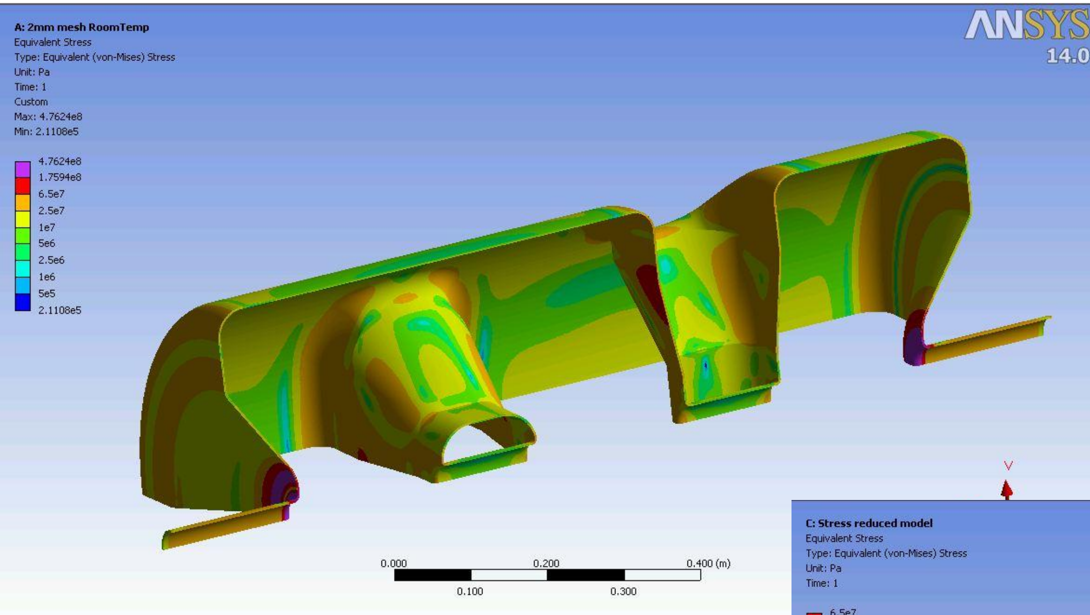
1: 700.6 MHz
2: 965.9 MHz
3: 1247.5 MHz
4: 1383.2 MHz
5: 1571.4 MHz
6: 1782.3 MHz
7: 1921.0 MHz
8: 2148.9 MHz
9: 2663.3 MHz
10: 2825.2 MHz
11: 2986.0 MHz
12: 3067.5 MHz
13: 3207.8 MHz
14: 3336.4 MHz
15: 3461.1 MHz
16: 3647.8 MHz
17: 3864.2 MHz
18: 3992.9 MHz



325 MHz, $\beta_0 = 0.82$
C. S. Hopper, ODU
T3P in ACE3P code suite (SLAC)

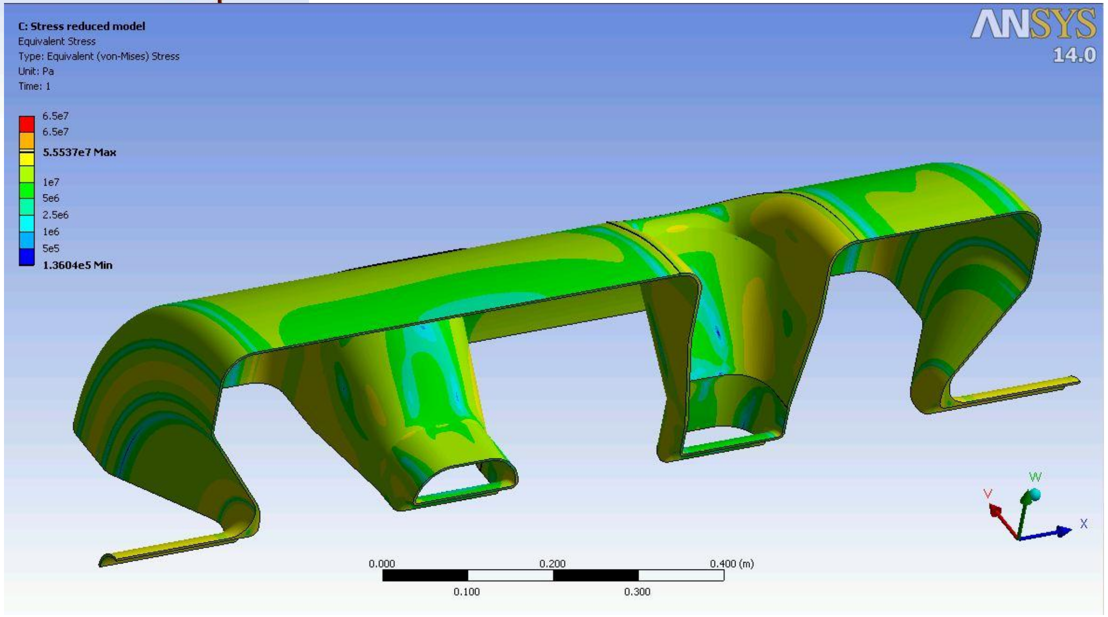
700 MHz, $\beta_0 = 1$
F. Krawczyk, LANL
MAFIA

Mechanical Analysis



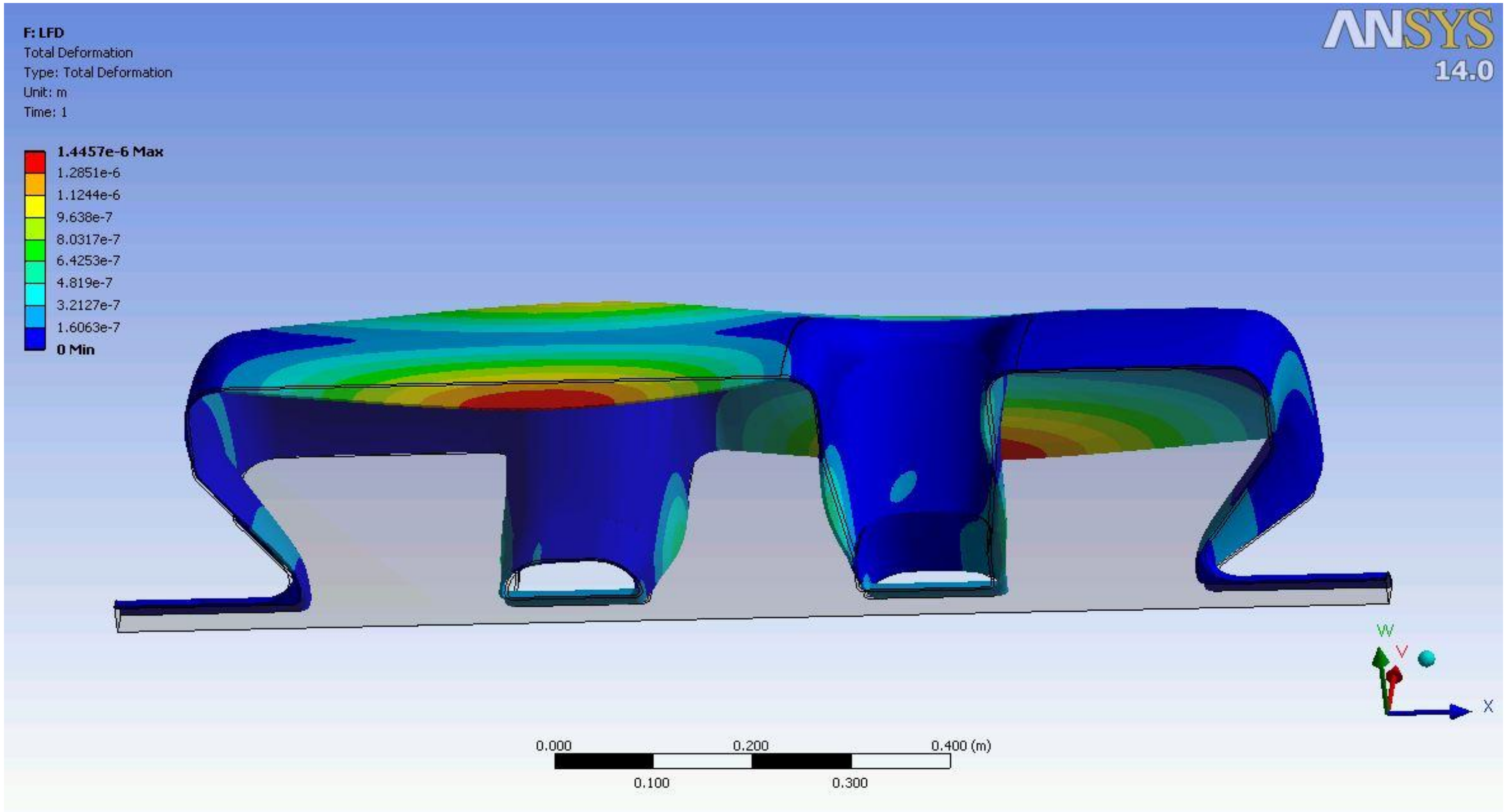
3 mm uniform thickness throughout the cavity. Stress red area shows exceeding yield strength (plastic deformation occurs)

Stress analysis – stress reduced cavity, 4mm thick spoke and reinforced re-entrant



H. Park, Jlab

Lorentz Force Detuning

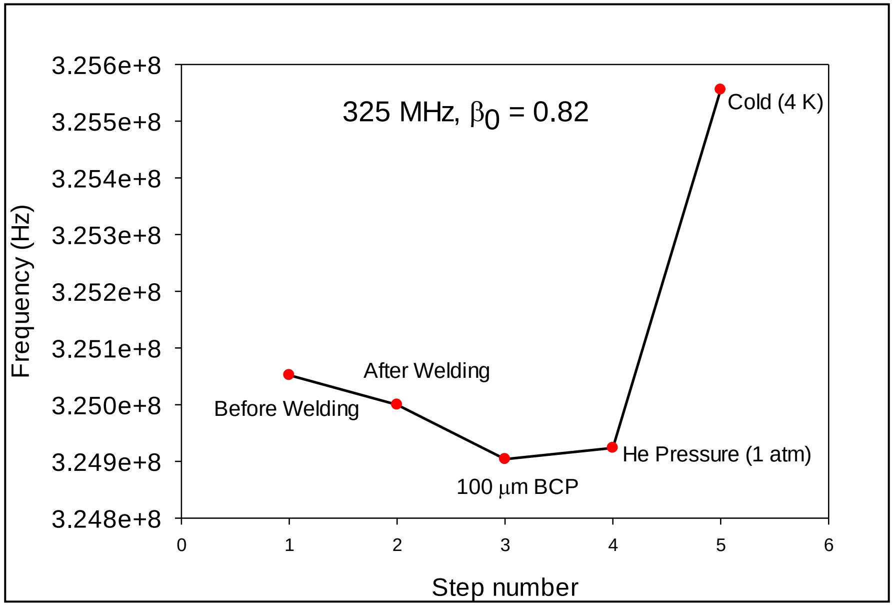


Based on 1 J energy content
3mm uniform thickness throughout the cavity.
Deformation scaled 24000X
Frequency before detuning 325614592.8 Hz
Frequency after detuning 325614219.8 Hz
Frequency shift -373.0156525 Hz

H. Park, Jlab

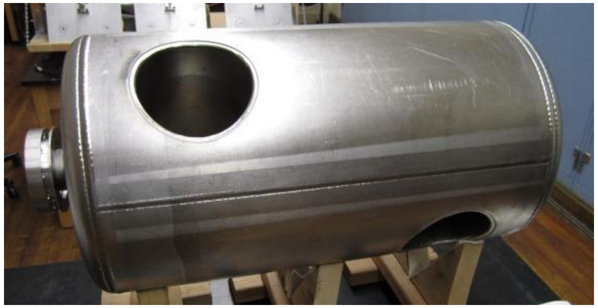
Frequency Shift by Process

Process	Effect	Frequency (Initial design) **(MHz)**	Frequency (final design) **(MHz)**
(1) Cavity in parts (before welding)	+54000/+37000 Hz/mm	325.0520192	324.4965052
(2) Cavity welded	base freq	325.000000	324.444486
(3) BCP (100 micron)	-960 Hz/µm	324.904000	324.348486
(4) Vacuum load (1 atm, He pressure at 4K)	+26 Hz/torr	324.923760	324.368246
(5) Cooldown (4K)	+2186 Hz/K	325.555514	325.000000



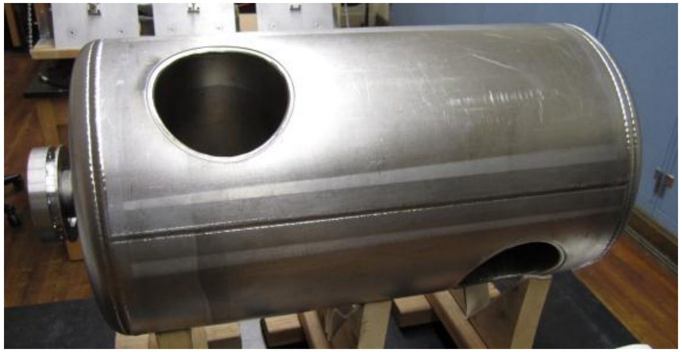
Fabrication

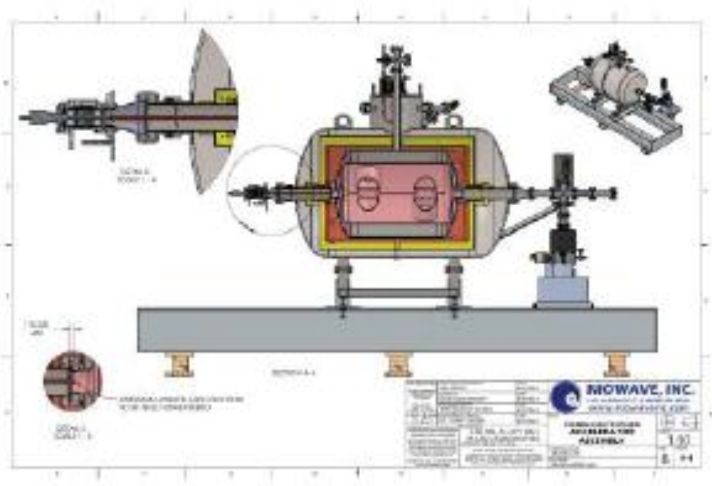
- 325 MHz, β = 0.82 and 1, single and double
  - Collaboration with JLab
- 352 MHz, β = 0.82 and 1, single and double
  - Collaboration with JLab
- 500 MHz, β = 1, double
  - Collaboration with Niowave
  - Collaboration with JLab

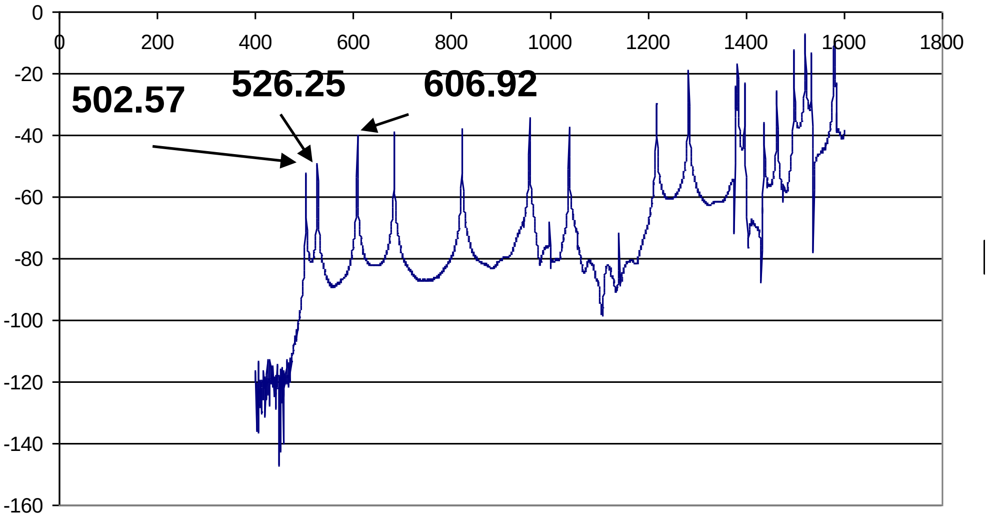


- 700 MHz, β = 1, single, double, and triple
  - Collaboration with Niowave, Los Alamos and NPS

500 MHz, $\beta_0 = 1$



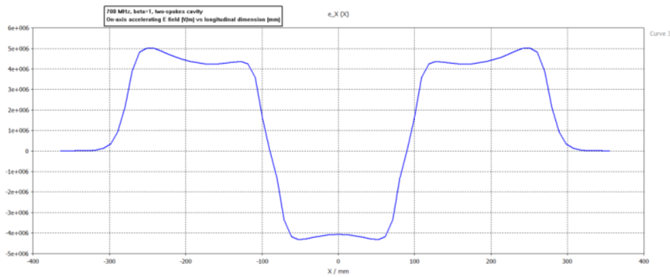


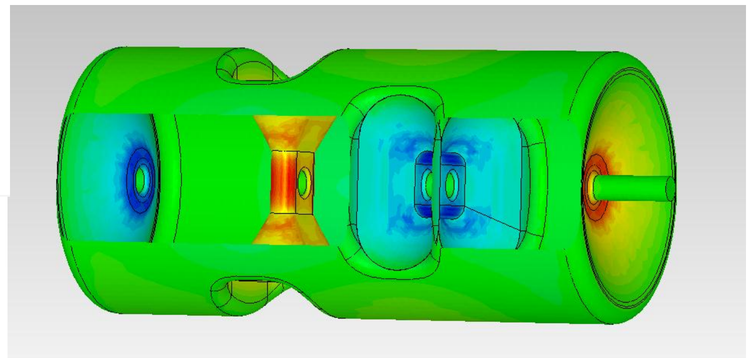


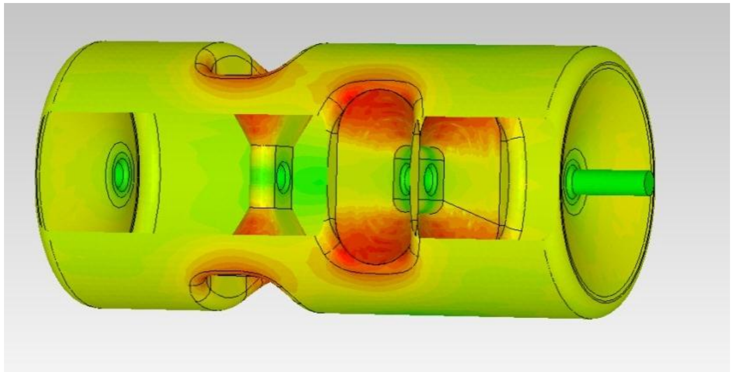
Subashini De Silva, ODU
Dmitry Gorelov, Niowave
Chase Boulware, Niowave
Terry Grimm, Niowave

700 MHz, $\beta_0 = 1$, Double-Spoke

Collaboration between Niowave, ODU, Los Alamos, NPS
Designed by ODU
Fabricated by Niowave







Summary

- Interest in high-velocity single- and multi-spoke cavities has been increasing
- The spoke geometry has a number of attractive features
- Many prototypes have been, or are being, developed in many institutions
  - 300 to 850 MHz, β from < 0.2 to 1
- $\beta \sim 1$ spoke cavities have been built and are undergoing test
  - They may be the first ones to accelerate beam
  - The first particle to be accelerated by a spoke cavity will probably be an electron
- Currently beginning fabrication process for 325 MHz, $\beta_0 = 0.82$ single-spoke and 500 MHz, $\beta_0 = 1.0$ double-spoke cavities

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- Jlab
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- Los Alamos
  - Frank Krawczyk
- Niowave
  - Chase Boulware
  - Dmitry Gorelov
  - Terry Grimm

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