HIGH-VELOCITY SPOKE CAVITIES

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OVERVIEW

- Introduction
  – History
  – Features of the spoke geometry

- High-velocity spokes
  - Applications
  - Electromagnetic Optimization
  - Multipacting
  - Processing
  - To date test results

- Concluding remarks

History

- Developed at ANL in the late 1980s along with the half-wave resonator
- From the early 1990s to early 2000s, single- and multi-spoke development mostly at ANL, LANL, and IPN
- The last decade has seen a significant increase in developing low- and medium-velocity cavities around the world
- Spoke cavities are now a popular option for the medium-velocity region and several projects are underway for the high-velocity region

	Frequency (MHz)	β
Fermilab	325	0.22*, 0.51*
IPN/ESS	352	0.15*, 0.35*, 0.50*
IHEP/IMP	325	0.12*, 0.21*, 0.4*, 0.52
RAON	325	0.3
RIKEN	219	0.303
LANL	350	0.175*, 0.21*, 0.48, 0.64
ANL	850, 345	0.30*, 0.4*, 0.5*, 0.63*
FZJ	760, 352	0.2*, 0.48*

***Fabricated and tested, yellow = in progress**

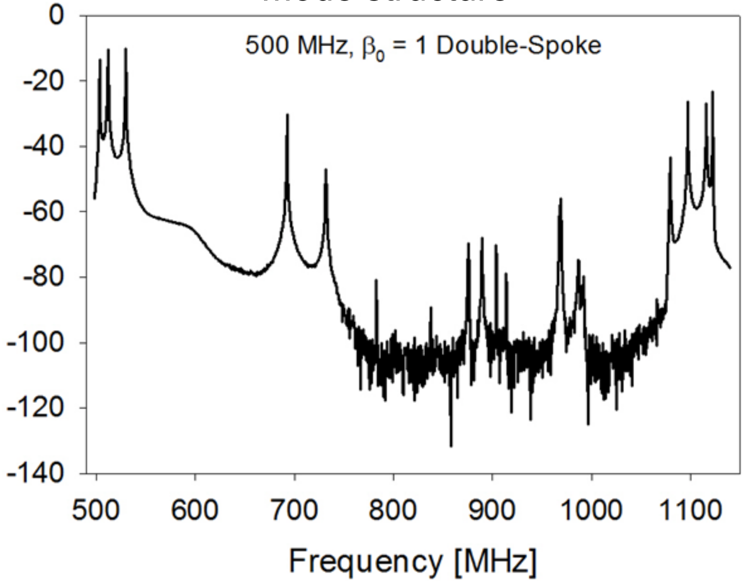
1990- ANL 850 MHz, β=0.3

Features of Spoke Cavities

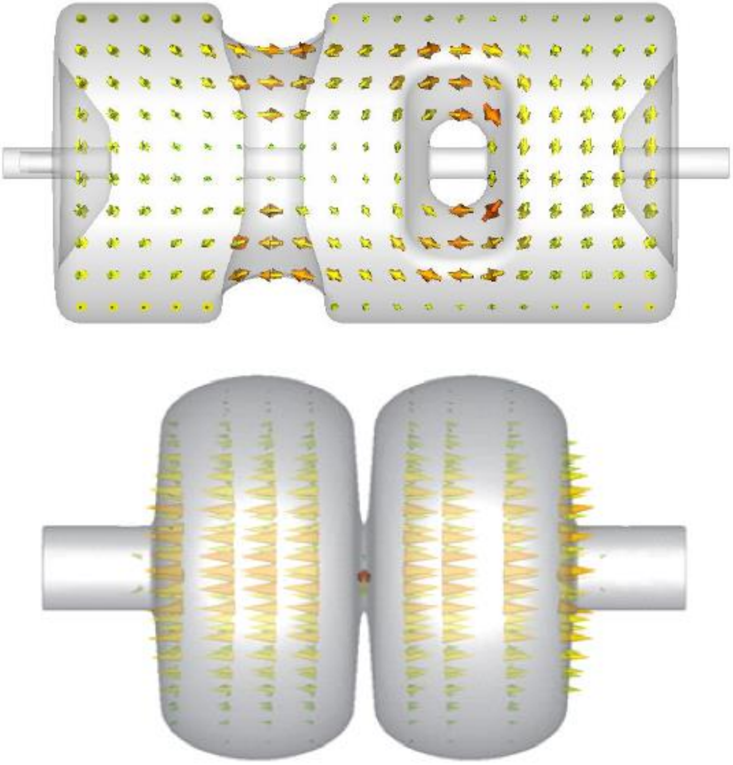
- Relative compactness
  - Between 20% - 50% smaller (radially) than a TM cavity of the same frequency

- Strong cell-to-cell coupling
  - Robust with respect to manufacturing inaccuracy
  - Less need for field flatness tuning
  - No LOMs, closest mode well separated

Mode structure



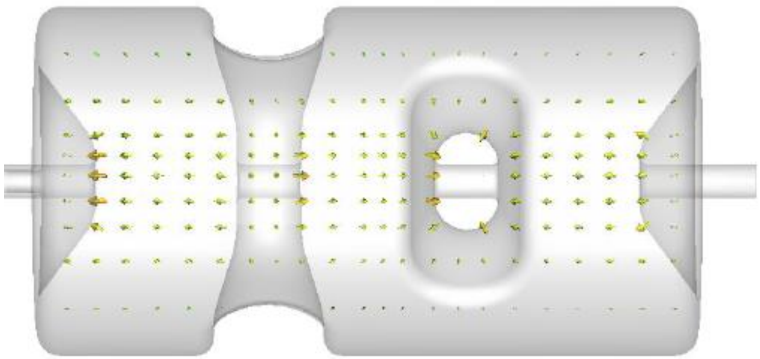
Coupling by magnetic field



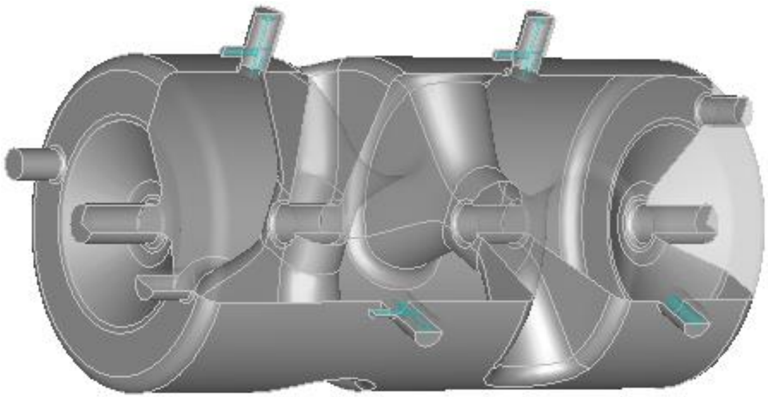
FEATURES OF SPOKE CAVITIES

- Low energy content, high shunt impedance

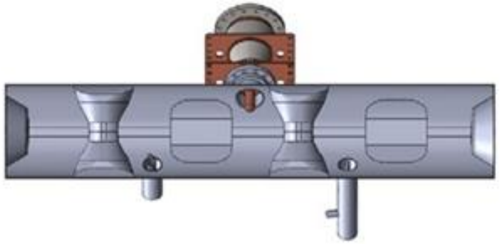
Electric field concentrated around beam line



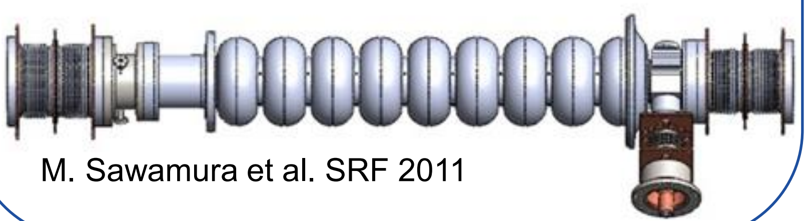
- Couplers located on outer conductor rather than in beamline space



650 MHz spoke



1300 MHz 9-cell elliptical

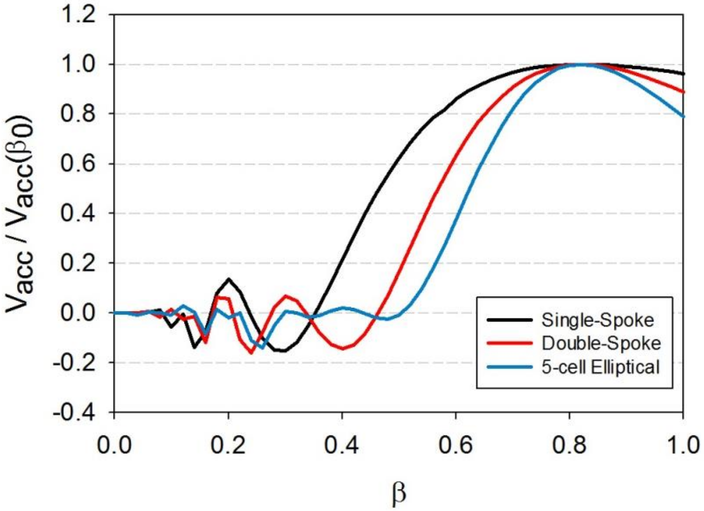


M. Sawamura et al. SRF 2011

- Mechanical rigidity

HIGH-VELOCITY APPLICATIONS

- Compact light sources (MIT, JLab, ODU, FREIA, JAEA)
  - 4-5 m long cw linac to accelerate electrons from a few MeV to tens of MeV
  - Lower frequency allows for 4.5 K operation
  - No sub-atmospheric cryogenic system



- High energy proton/ion linacs
  - Taking advantage of large velocity acceptance and fewer frequency transitions
  - ODU 325 MHz, $\beta_0 = 0.82$ double-spoke cavity: $V_{acc}/V_{max} > 96\%$ for $0.74 \leq \beta \leq 0.92$ (460 MeV to 1.5 GeV for protons)

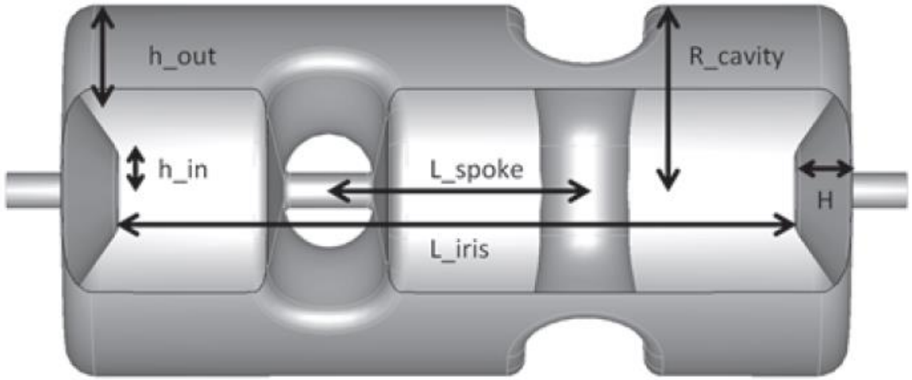
- ERL combined with laser Compton scattering for non-destructive assay system for nuclear materials in spent fuel (JAEA)

PROPOSED PROJECTS

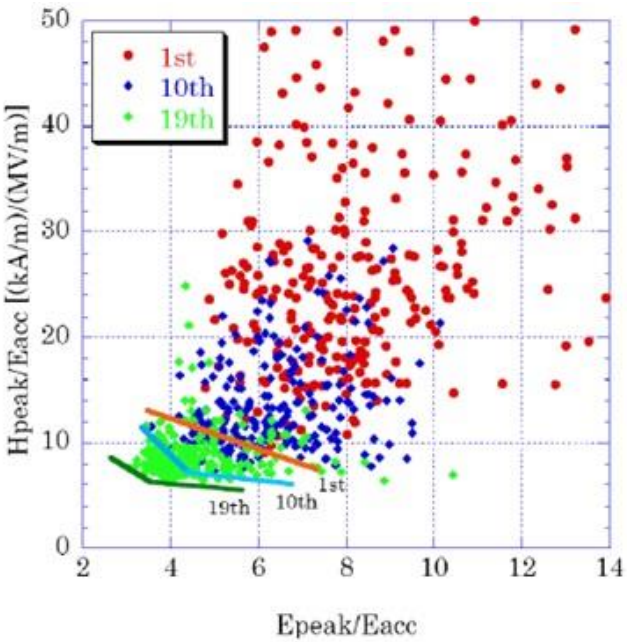
	Particle	Cavity type
MIT/JLab	electron	352 MHz, β_0 = 1 double-spoke
ODU*	electron	500 MHz, β_0 = 1 double-spoke
ODU*	proton/ion	325 MHz, β_0 = 0.82 single-spoke
FREIA	electron	352 MHz, β_0 = 1 double-spoke
JAEA	electron	325 MHz, β_0 = 1 single-spoke
Niowave*	electron	700 MHz/350 MHz β_0 = 1 double-spoke

***Fabricated and tested, yellow = in progress**

High-Velocity Design Optimization



- N-parameter optimization is non-trivial



325 MHz, β_0 = 1.0 optimized results from two methods:

- Ep/Eacc = 3.7 (ODU), 3.7 (KEK)
- Bp/Eacc = 7.1 (ODU), 7.5 (KEK)
- R/Q = 737 (ODU), 691 (KEK)

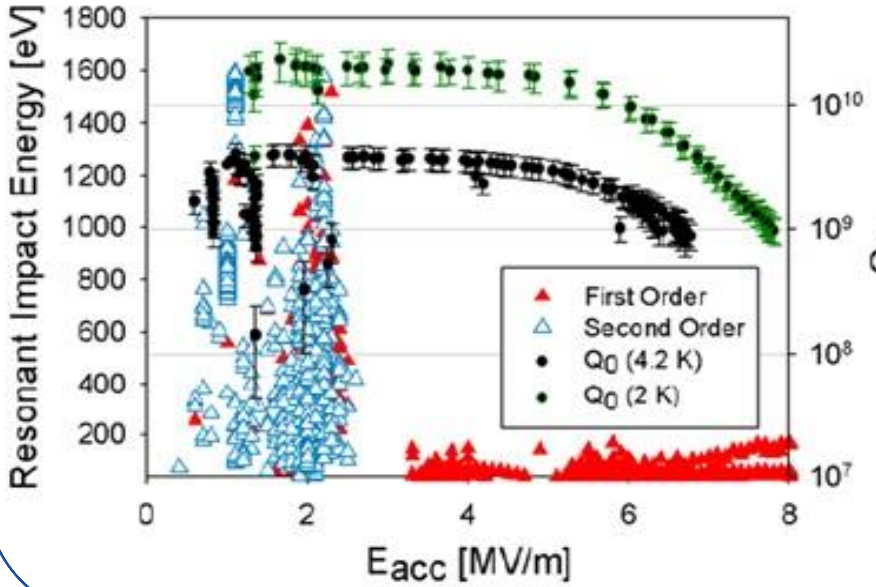
Multi-objective optimization,
M. Sawamura et al. SRF 2011
T. Kubo et al. LINAC 2014

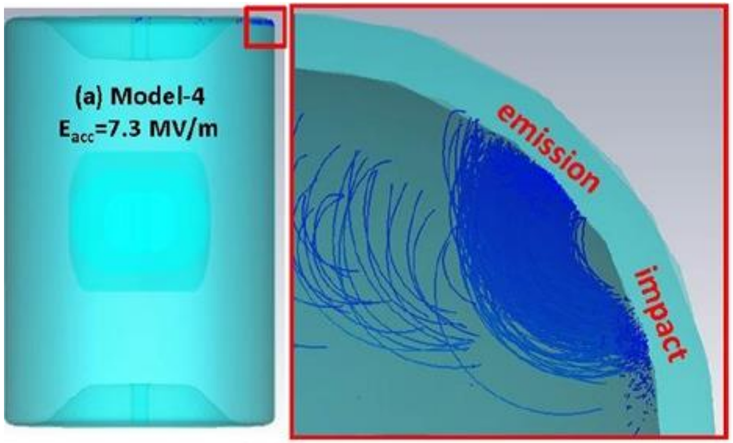
C.S. Hopper and J.R. Delayen, PRSTAB, **16**, 102001, (2013).

also see N. Solyak et al. SRF 2009

PREDICTION OF MULTIPACTING

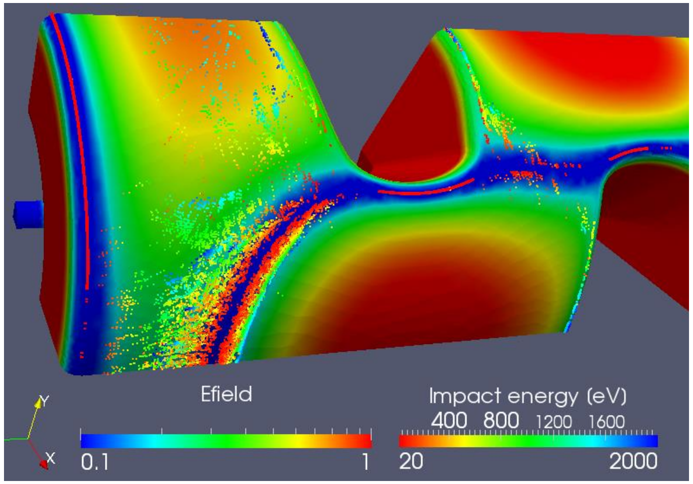
Initial test of 325 MHz, β_0=0.82 single-spoke cavity (ODU/Jlab)





325 MHz, β_0 = 1 (CST PS)
T. Kubo et al., IPAC 2015

Multipacting activity predicted below 2.5 MV/m using Track3P. First test verified this.
Easily processed.



352 MHz, β_0 = 1 (Track3P)
F. He, JLab

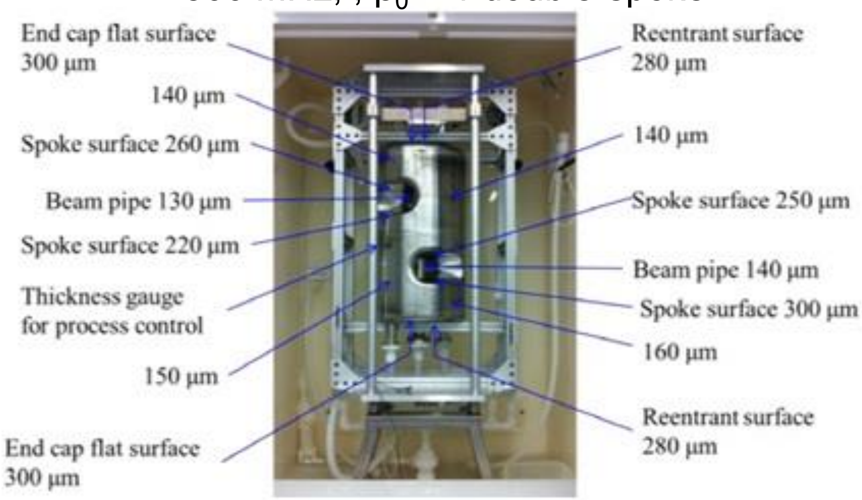
C.S. Hopper and J.R. Delayen, LINAC 2012
C.S. Hopper et al. LINAC 2014
K. Ko et al., LINAC 2010

Cavity Processing

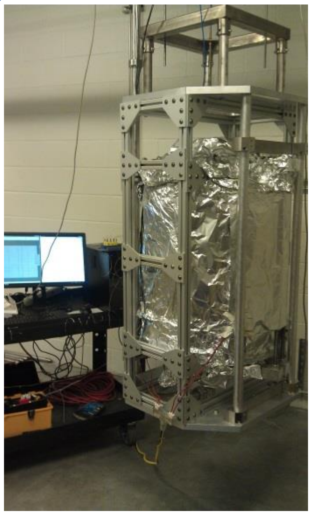
Processing Steps:

- 120-150 µm bulk BCP (at Niowave and Jlab)
- 600 ˚C, 10 hr H degassing (Fermilab and Jlab)
- 10-30 µm light BCP
- HPR (Jlab)
- Class 10 cleanroom assembly (Jlab)
- 120 ˚C, 48 hour bake

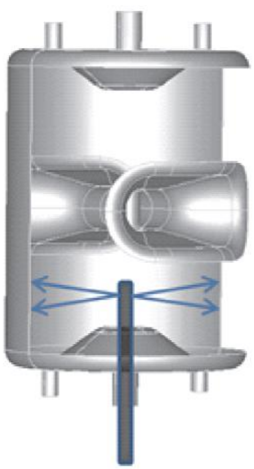
500 MHz, , β_0 = 1 double-spoke

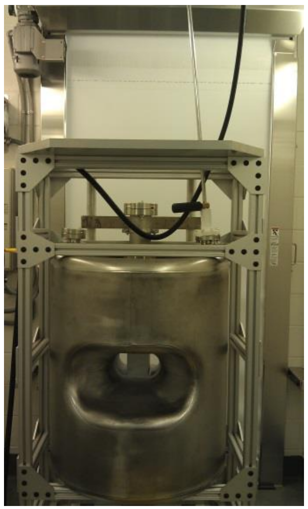


HyeKyoung Park et al. LINAC 2014



325 MHz, β_0 = 0.82 single-spoke





CAVITY PERFORMANCE (4 K)

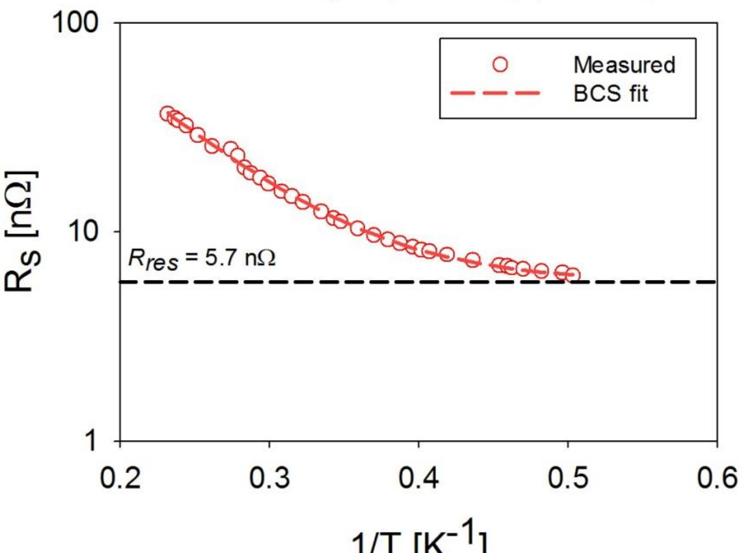
Frequency	500 MHz (ODU)	325 MHz (ODU)	700 MHz (Niowave)	350 MHz* (Niowave)
4 K				
V_{acc} [MV]	2.7	9.1	3.2	8.7
E_{acc} [MV/m]	4.5	12	5.0	6.8
E_p [MV/m]	17	43	22	34
B_p [mT]	34	72	39	55

*During pulsed operation

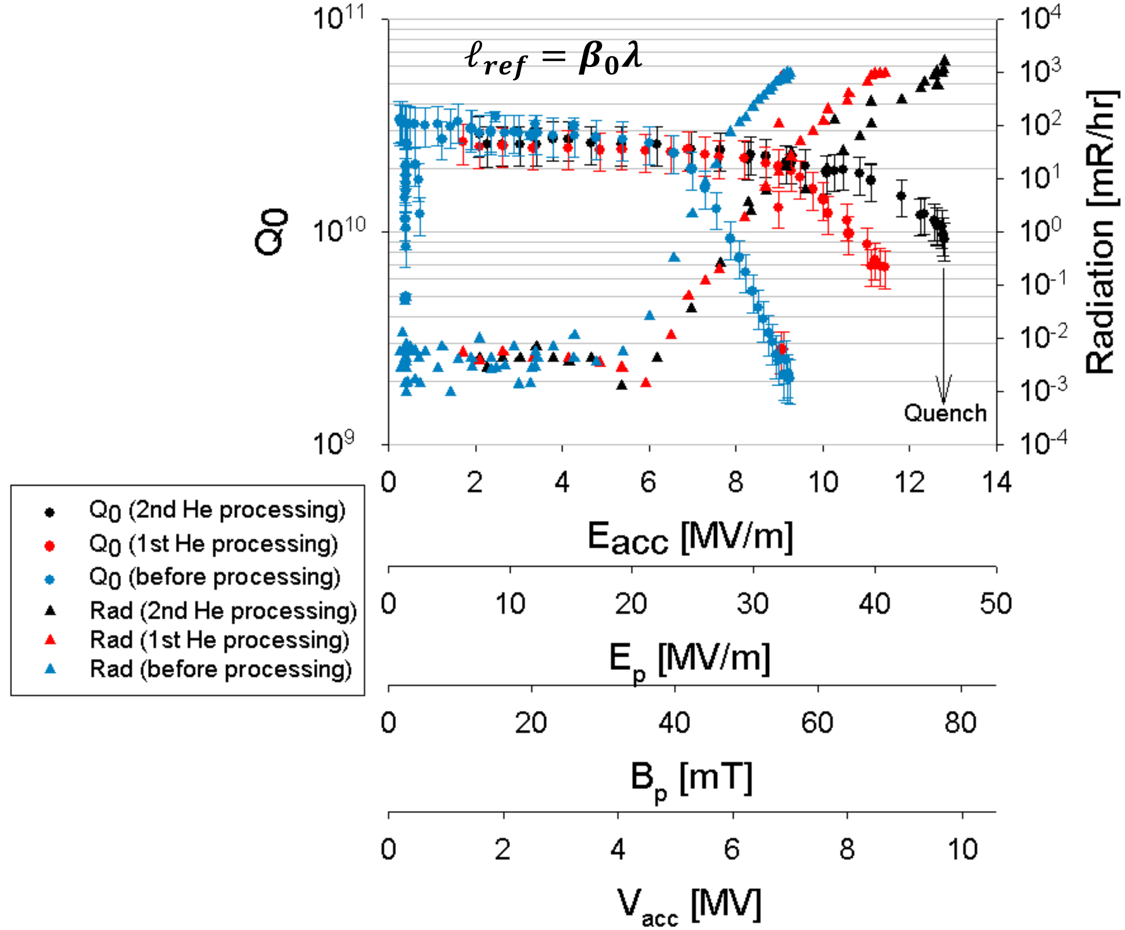
- 500 MHz double-spoke cavity was limited by TB
- 325 MHz single-spoke cavity improved significantly after helium processing
- No hard quenches seen in either of the Niowave double spokes- ultimate performance not yet reached

C.S. Hopper et al. LINAC 2014
T. Grimm et al. FEL 2013

CAVITY PERFORMANCE (2 K)



325 MHz, β_0 = 0.82 single-spoke cavity
2 K



C.S. Hopper et al. TUPB071, SRF 2015

Concluding Remarks

- Spoke cavities have been developed, fabricated, and tested for more than 25 years and now span $\beta < 0.2$ to $\beta = 1$.
- For certain high-velocity applications, spoke cavities are currently the best available technical option.
- Electromagnetic optimization is non-trivial and consideration of fabrication, handling, and processing is essential throughout the process. Like other TEM-class cavities, there are some challenges, but no showstoppers.
- Multipacting is part of the TEM structure experience. During our tests, it was easily processed and did not recur.
- High-velocity spoke cavities have been fabricated and tested. To date, the results are promising…

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- LANL – Frank Krawczyk