TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Douglas W. Storey

Toohig Fellowship Candidate

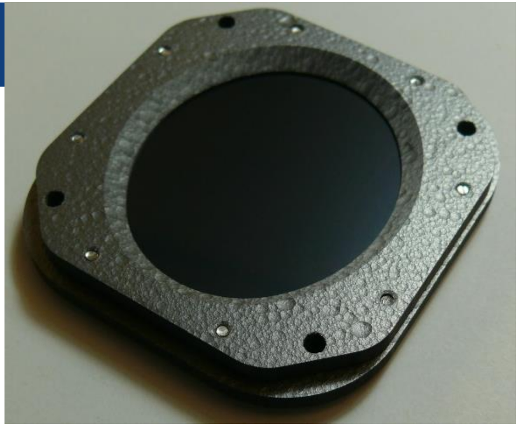
Joint LARP CM28/HiLumi Meeting

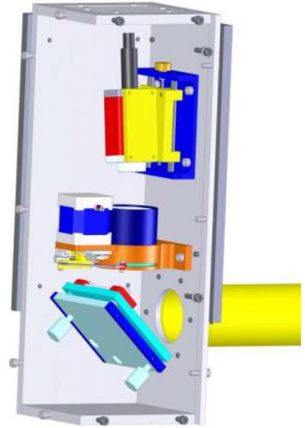
April 24, 2017

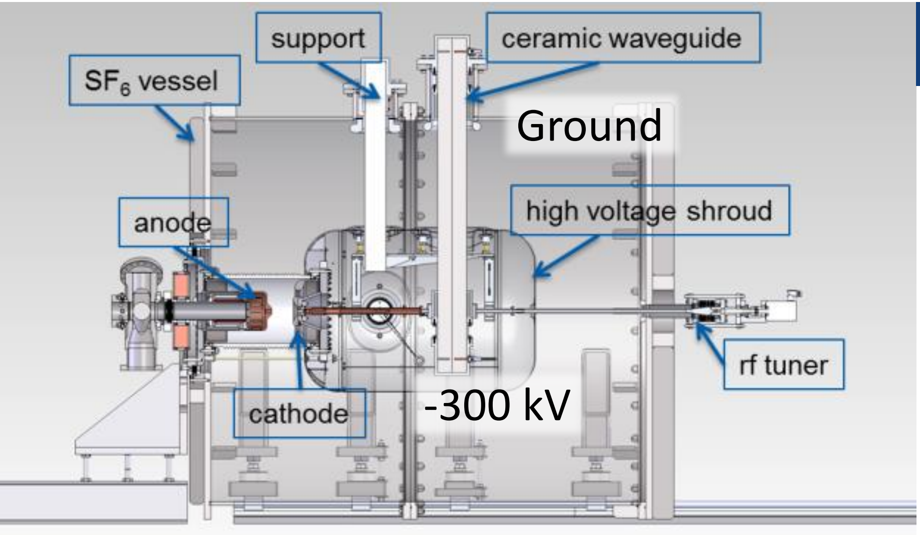
Overview of Research Background

Development of beam diagnostics systems

- Developed the view screen beam profile monitors for ARIEL eLinac
  - Uses scintillator and OTR screens
- Compton polarimeter for Qweak experiment at Jlab – (during BSc)







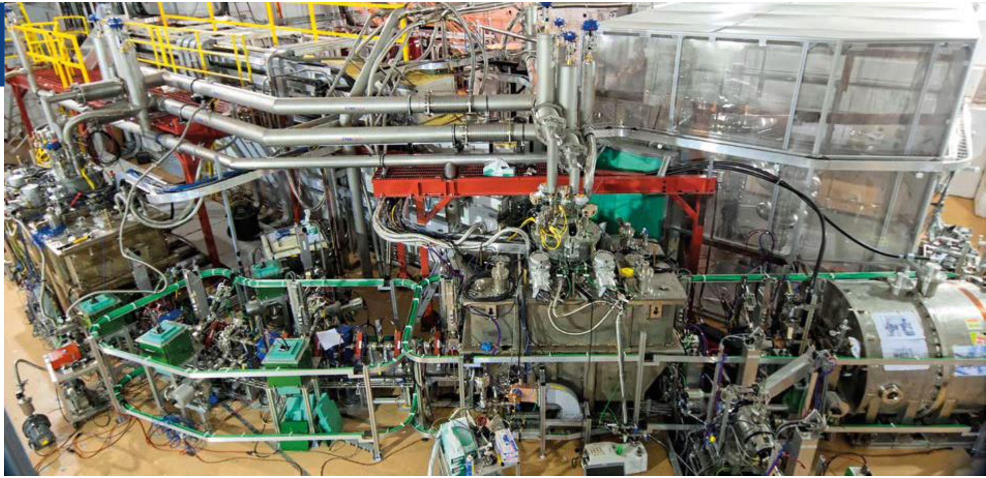
Development of electron source

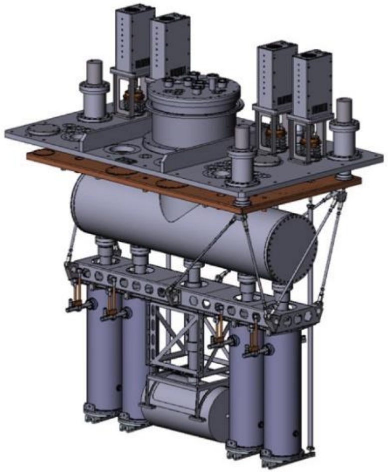
- Developed a ceramic waveguide for a RF modulated DC electron gun
  - Transmits 100 W RF power across 300kV DC gap
  - Optimized geometry via RF simulations
  - Performed measurements on bench and after installation

Overview of Research Background

Commissioning of eLinac systems

- Electron diagnostics systems
  - Low power commissioning of view screens
  - High power beam tests in coming months
- 1.3 GHz cavity systems
  - Investigated energy and phase instabilities

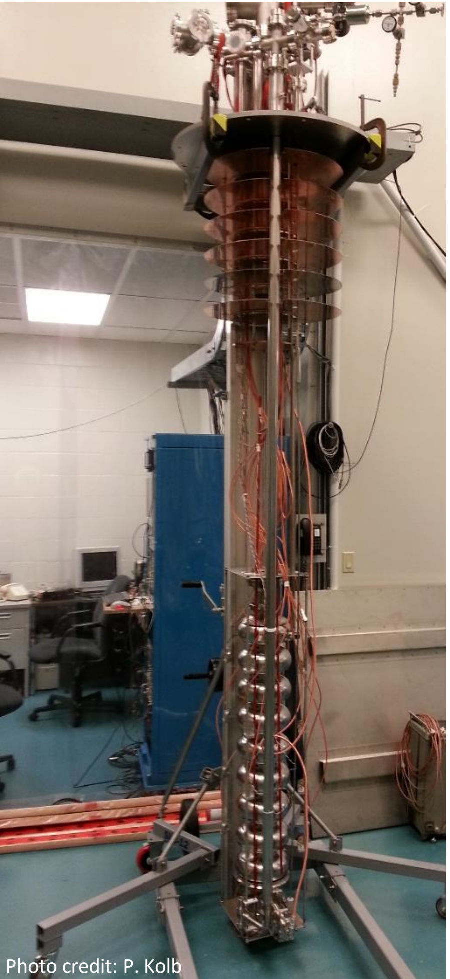




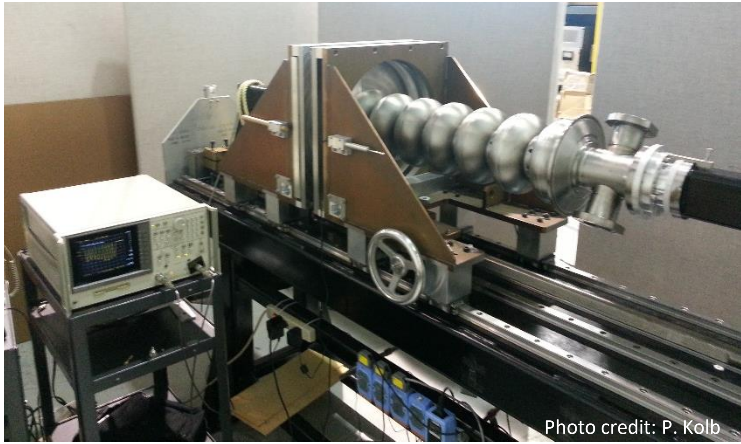
SC Linac Operations

- Operation of ISAC 40MV SRF linac
  - 40 quarter wave resonator cavities
- Provide SRF expert support
  - On call 24hr/day operations support

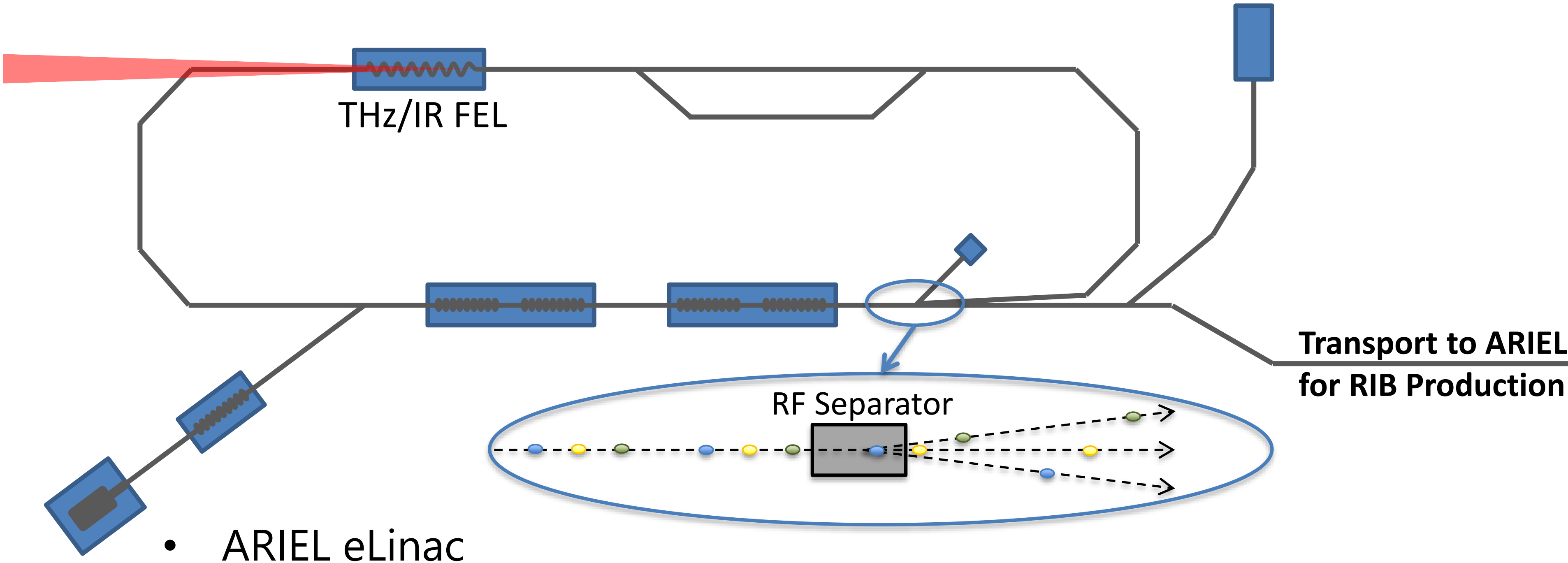
SRF Activities



- Some main SRF activities I have been involved with:
  - Operations and commissioning of SRF systems
  - 2K and 4K vertical cavity tests
    - QWR, 1.3 GHz cavities
  - Cavity processing
    - BCP, HPWR, assembly
  - Tuning, beadpull measurements
  - Fundamental studies of SRF materials using μSR
  - SRF cavity development
    - This has been the main focus of PhD



PhD Research – Development of an RF Deflecting Cavity



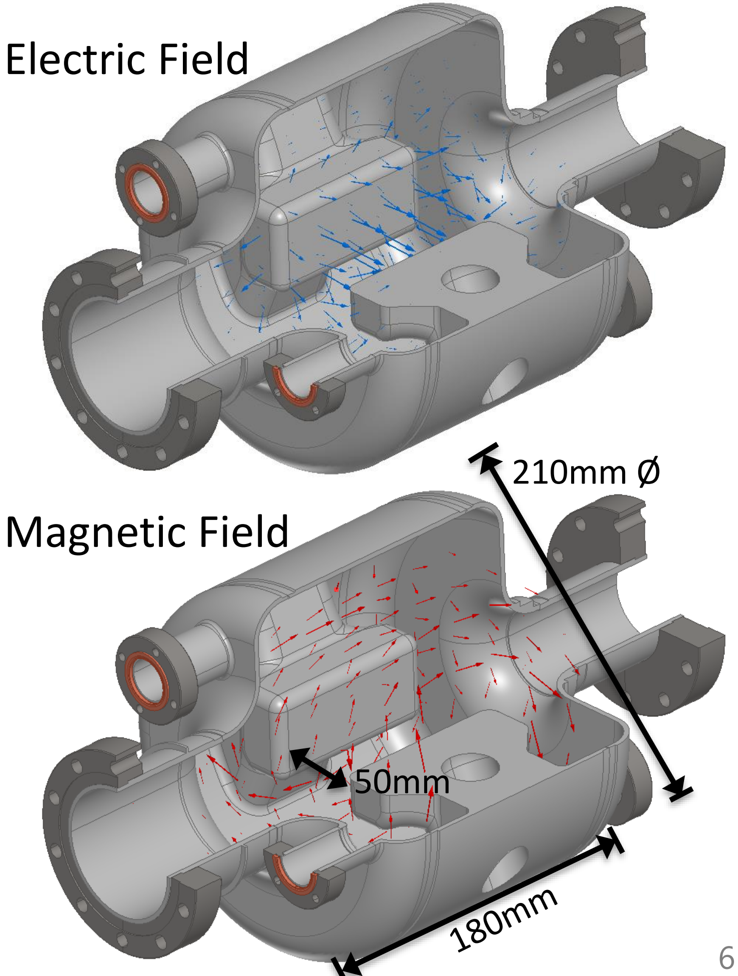
- ARIEL eLinac
  - 30 – 50 MeV, 10mA CW driver for rare isotope beam production
  - Will be upgraded with a recirculation loop to operate as an ERL
    - Simultaneous beam delivery to RIB production and ERL requires RF separation

- Cavity performance parameters:

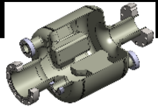
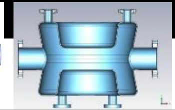
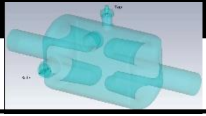
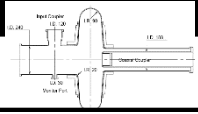
  Superconducting Niobium cavity at 4.2 K

Resonant frequency:	650 MHz	
Deflecting voltage:	0.3	(0.6) MV
Shunt impedance:	625 Ω	
Geometry factor:	99 Ω	
Peak electric field:	9.5	(19) MV/m
Peak magnetic field:	12	(24) mT
RF power dissipation:	0.35	(1.4) W

- Geometry modified from RFD design for higher shunt impedance, shorter length

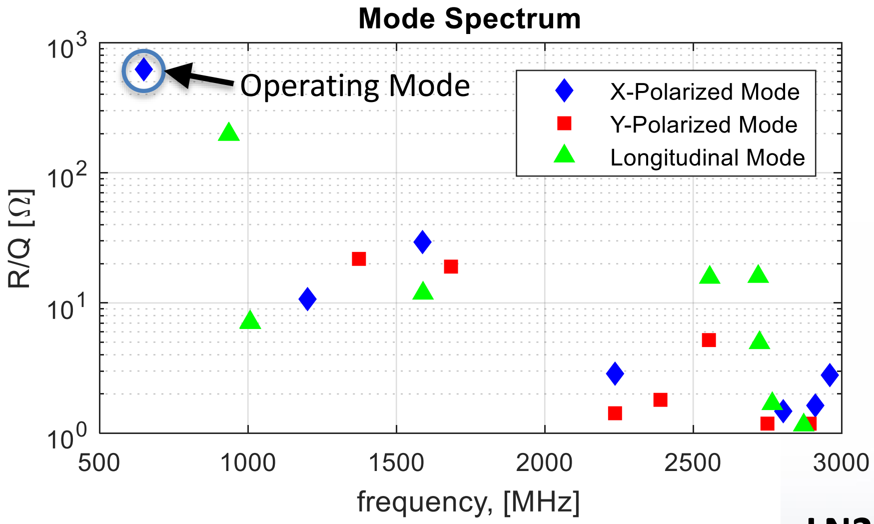


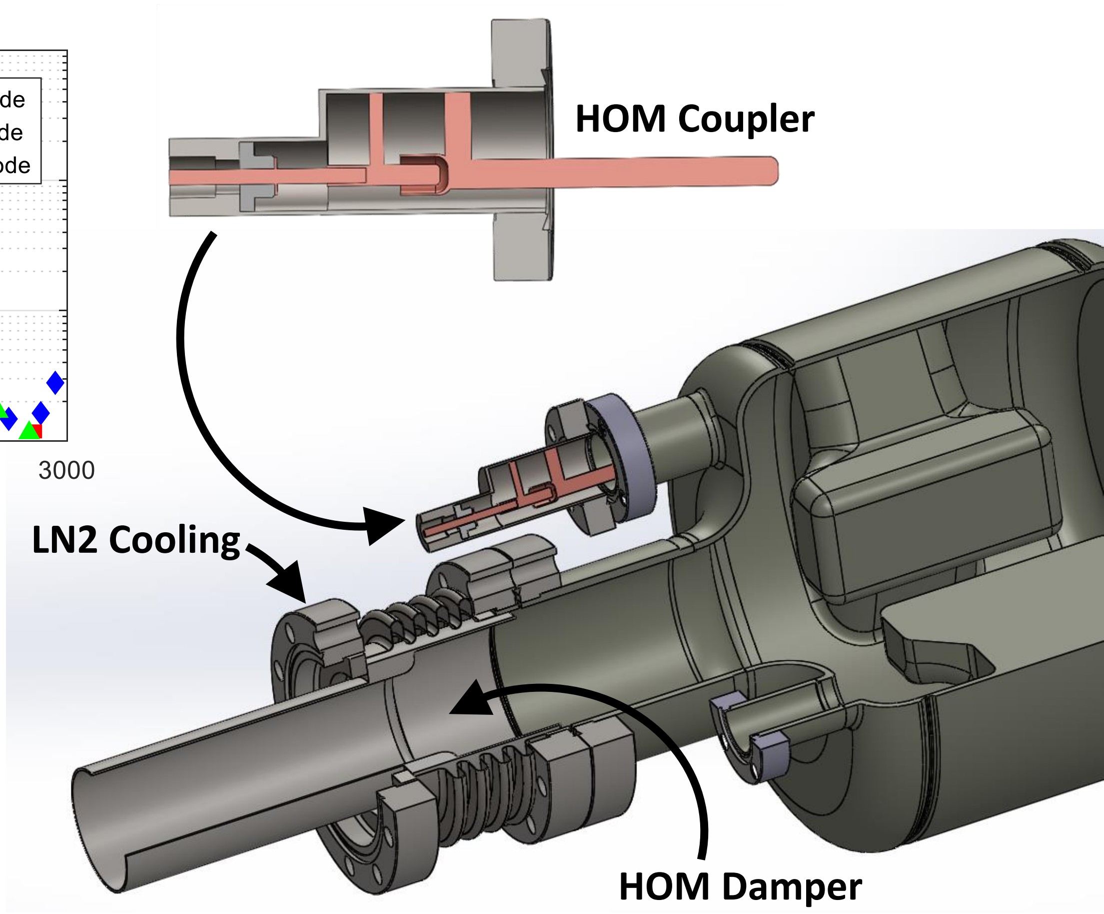
Comparison to other crab & deflecting cavities

	TRIUMF	LHC RFD[1]	LHC QWR[1]	UK 4R[2]	KEK Crab[3]	Jlab 4Rod[4]	Cornell ERL Deflector[5]	
								
Operating freq.	650	400	400	400	509	499	1300	MHz
Temp	4.2	2	2	2	2.8	300	300	K
$\frac{L_{cav}}{\lambda/2}$	0.76	1.5	1.3	1.3	0.9*	0.92	0.95	
$\frac{\text{Max width}}{\lambda/2}$	0.88	0.75	0.78	0.76	2.9	0.97	2	
$\frac{\text{Aperture}}{\lambda/2}$	0.22	0.22	0.22	0.22	0.63	0.05	0.3	
$R_\perp R_s$	6.2×10^4	4.6×10^4	3.7×10^4	5.8×10^4	1.0×10^4	1.2×10^6	9.9×10^4	Ω^2
Operating $V_\perp$	0.3 – 0.6	3.4	3.4	3.4	2.8	< 0.6	< 0.05	MV
E_p at 0.3MV	9.5	2.9	3.3	3.2	4.3			MV/m
B_p at 0.3MV	12	4.9	6.4	6.1	12			mT

[1] International Review of the Crab Cavity Performance for HiLumi, April 3-5 2017 [2] WEPWO056, IPAC2013 [3] THXM02, EPAC08 [4] MOP12, LINAC96 [5] WEPMS004, PAC07

Higher Order Modes

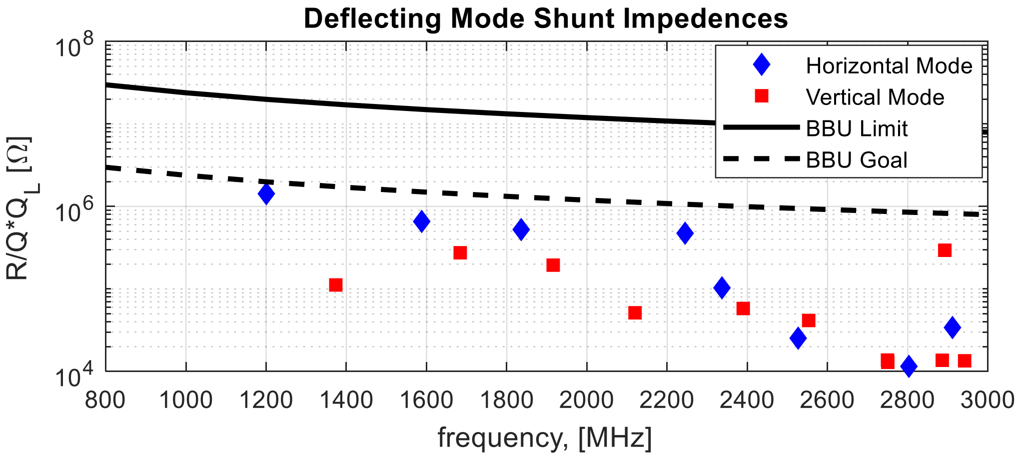


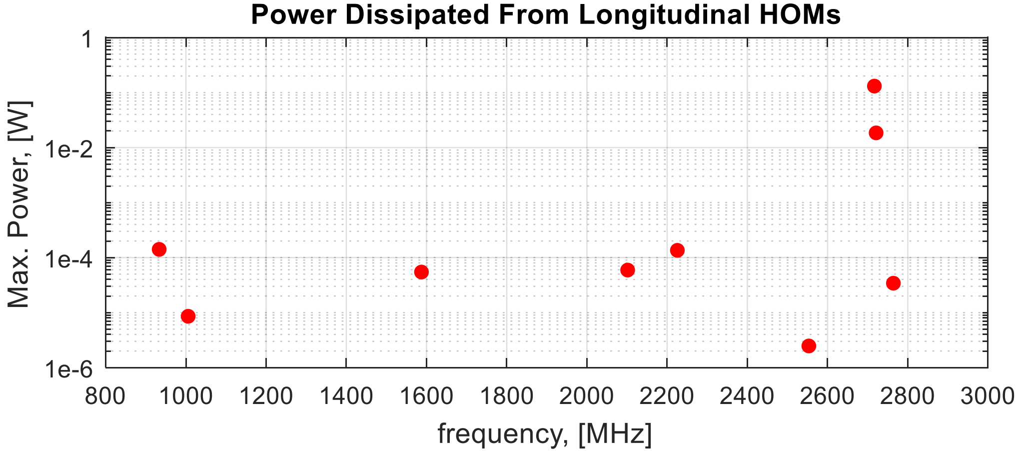


- HOM damping
  - HOM coupler with 650 MHz filter
    - Transfers HOM power to an external load
  - Resistive beam pipe damper
    - Cooled by liquid nitrogen

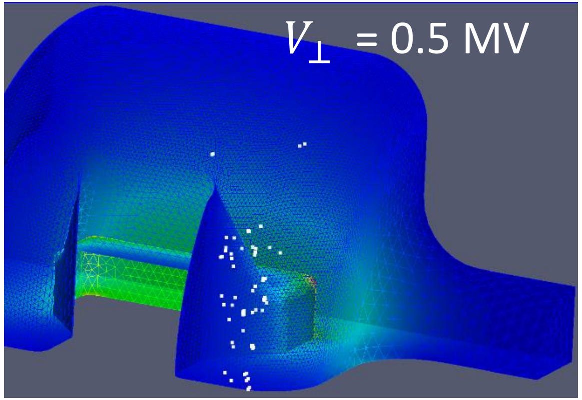
HOM Damping Simulations

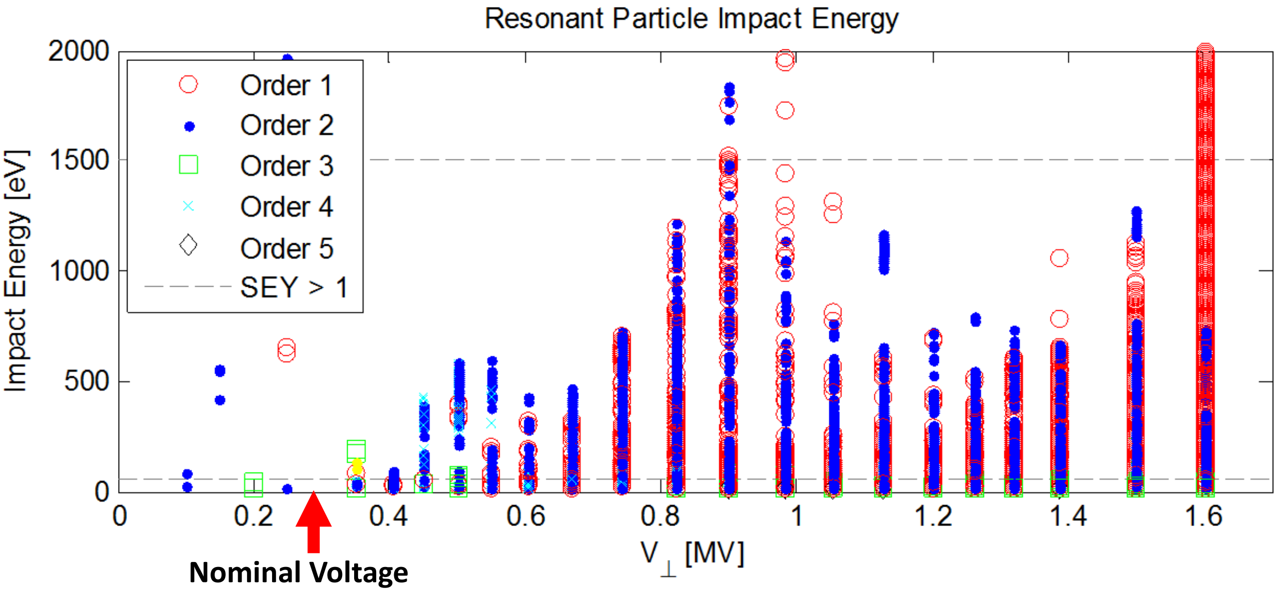
- Simulations performed in HFSS, confirmed using ACE3P
- Deflecting modes
  - All modes sufficiently damped
  - Limiting process is multipass BBU
- Longitudinal modes
  - Most modes far from resonant frequency
  - Even on resonance, minimal power dissipated
- Total power dissipation
  - Majority of power is damped by the HOM damper
    - < 1 W through HOM coupler
    - < 1 mW on beam pipe damper





Multipacting Analysis

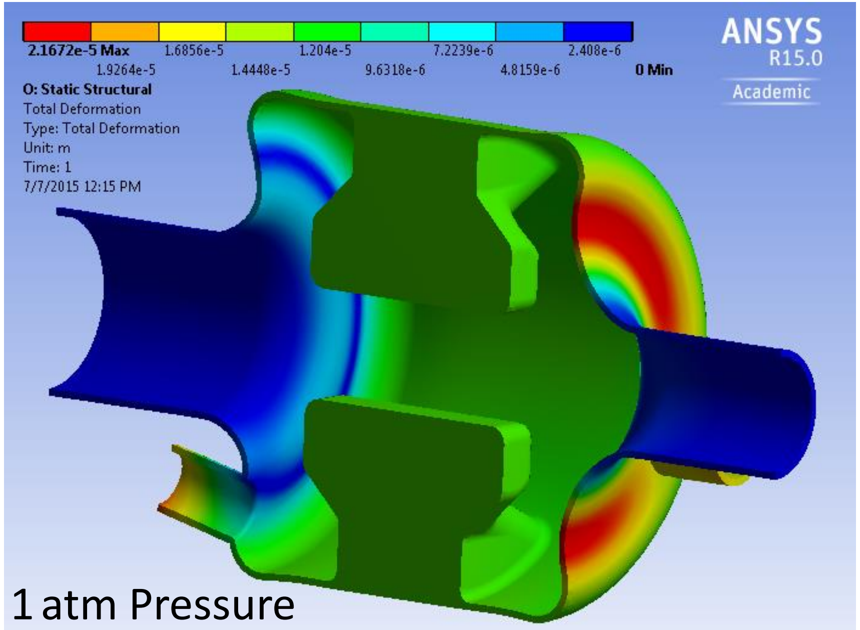




- Cavity analyzed for multipacting using TRACK3P
- Similar impact energy response as RFD and DQW cavities
  - Experience at ODU, BNL, and CERN suggest MP seen at low voltage may be processed with relative ease
    - S.U. De Silva and J.R. Delayen, PRST-AB **16**, 082001 (2013)
    - B. Xiao, et. al., PRST-AB **18**, 041004 (2015)

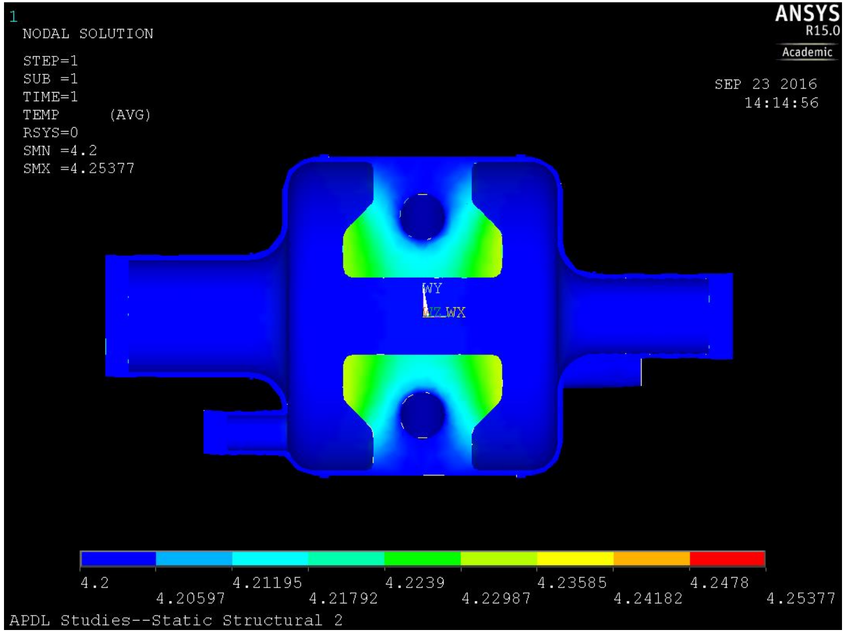
- Ridges machined from solid Niobium, 3mm wall on body
  - Decreases pressure sensitivity to ~ 1 Hz/mbar
  - Minimal temperature rise of ridge: $\Delta T < 0.1$ K

Cavity Deformation:



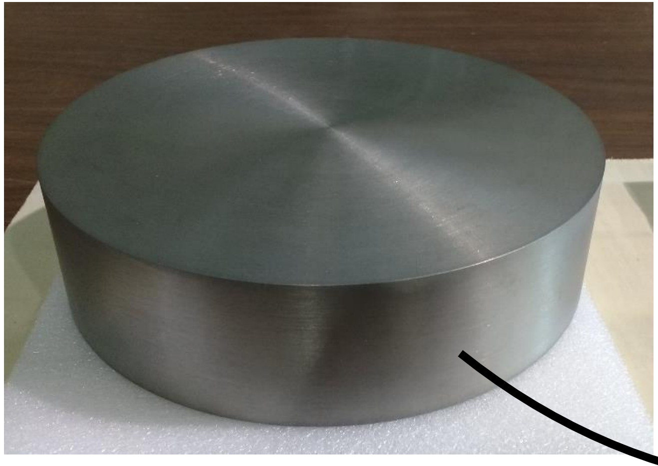
1 atm Pressure

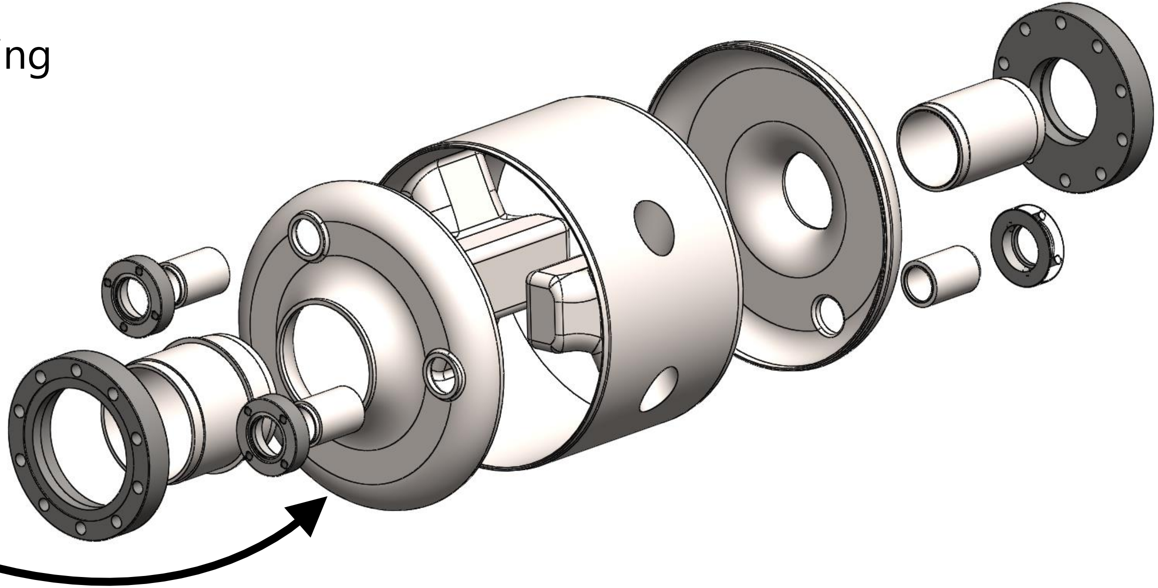
Thermal Response at 0.6MV:



Fabrication Methods

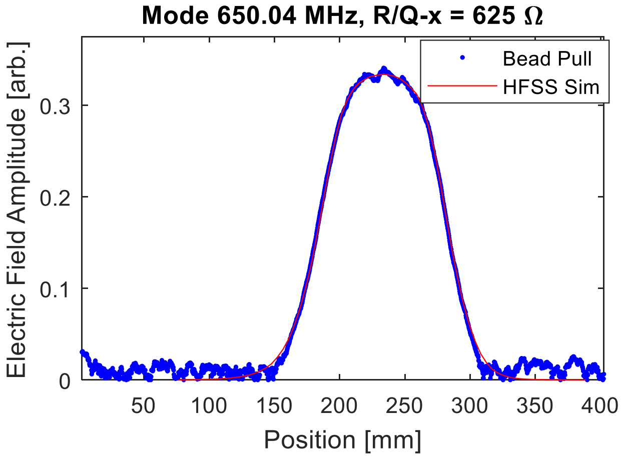
- Low performance requirements of cavity allow for development of non-standard fabrication methods
  - Machining from bulk *reactor grade* Niobium
    - Lower purity than standard SRF cavity material
    - RRR of 45 compared to usual ~300
  - Tungsten Inert Gas (TIG) welding

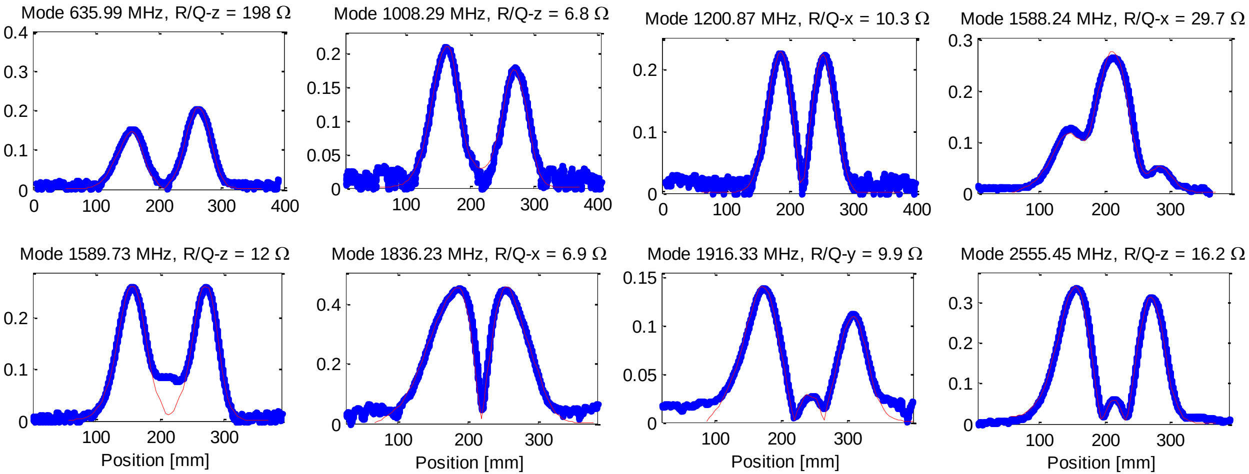




Copper Prototype Studies

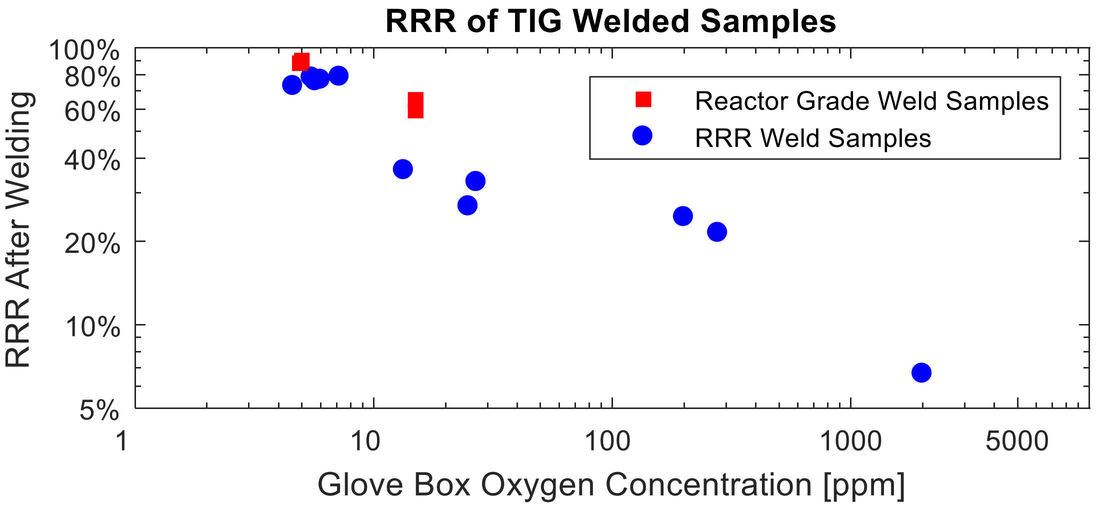
- Copper cavity fabricated to test fabrication steps
- Bead pull measurements of operating and HOMs

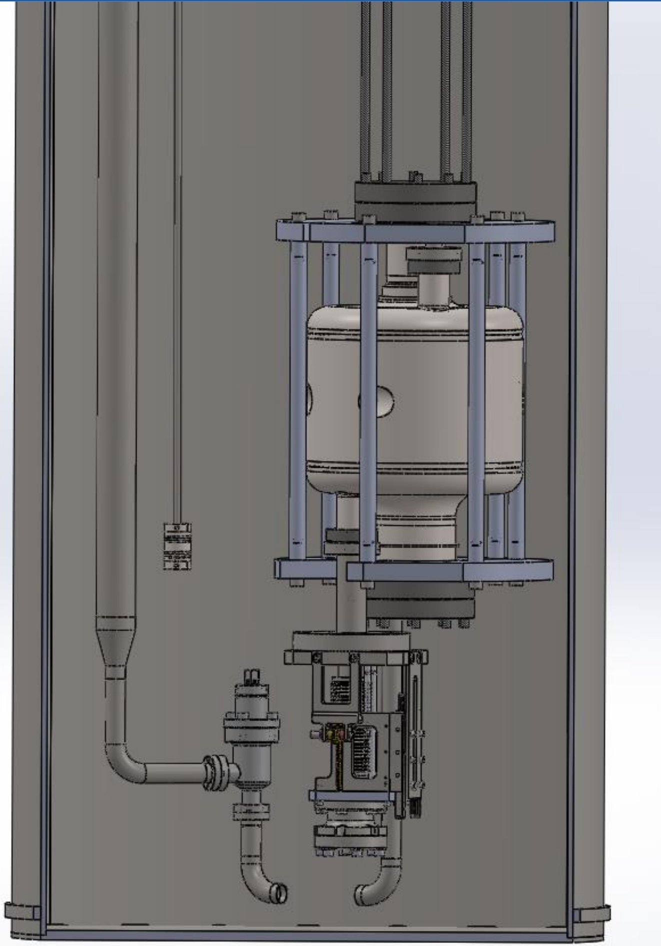




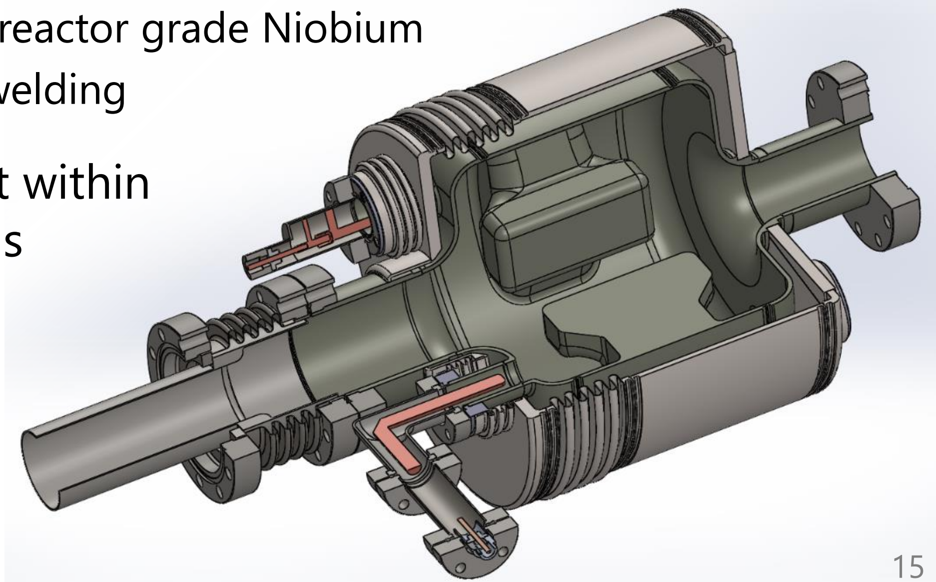
Characterization of TIG Welding

- Cavity is being fabricated in house
- Welded in an ultrapure Argon filled glove box
- TIG weld studies performed:
  - O2 < 10ppm results in minimal degradation of welds
  - RRR dropped from 45 to 41 after weld





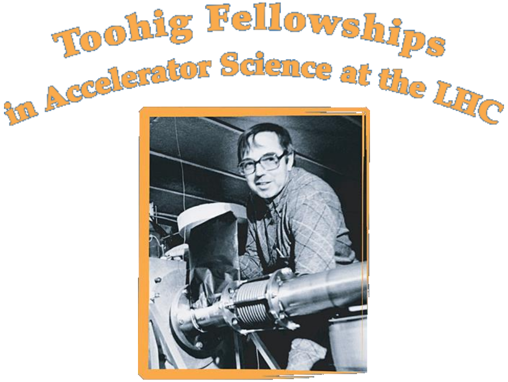
- A deflecting mode cavity has been designed with:
  - High shunt impedance
  - Small transverse and longitudinal dimensions
  - Good HOM properties
- In-house fabrication has commenced using:
  - Bulk reactor grade Niobium
  - TIG welding
- Cold test within 2 months



Interests in LARP, so far...

- Beam tests of crab cavities in SPS:
  - Beam based measurements of beam loading and HOM response of cavities
    - Effectiveness of HOM couplers
    - Determine the impact of the HOMs on beam properties
  - Quantifying effects of crab cavities on the beam
    - Impact on beam halo
    - How to minimise effects of cavities when offline or tripped
    - Stability of the system online
  - Preparation of cryomodules for crab cavities
- Looking forward to learning about other opportunities within the collaboration!

LARP



HiLumi
HL-LHC PROJECT

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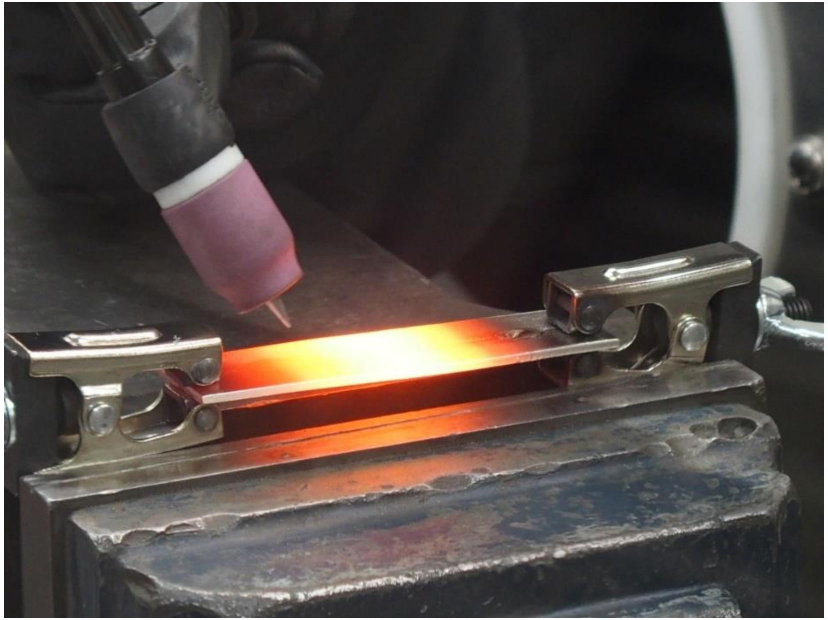
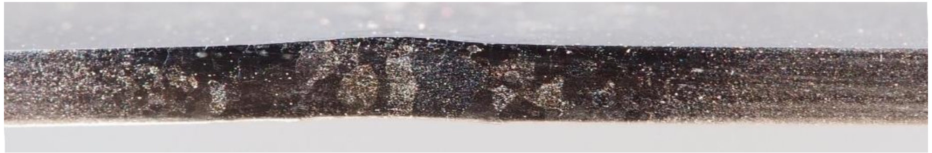
Weld Studies

- Development of TIG welding procedures
  - Building on work started by Chris Compton at MSU:
    - C. Compton, *et. al.*, WEP01, SRF2007



- Full penetration welds:

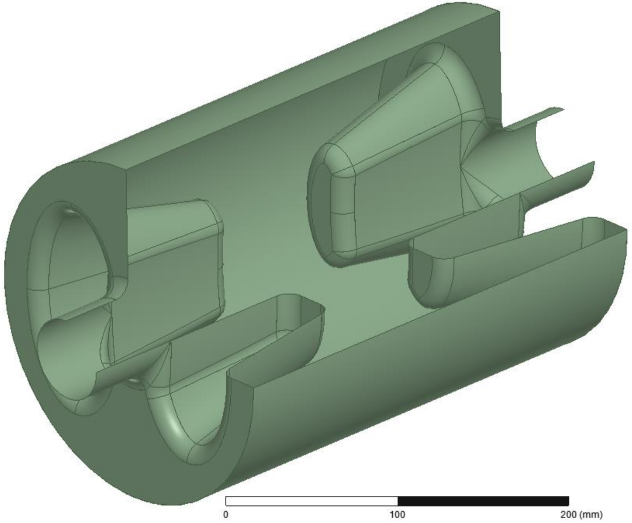
- Heat affected zone (HAZ) of ~12mm



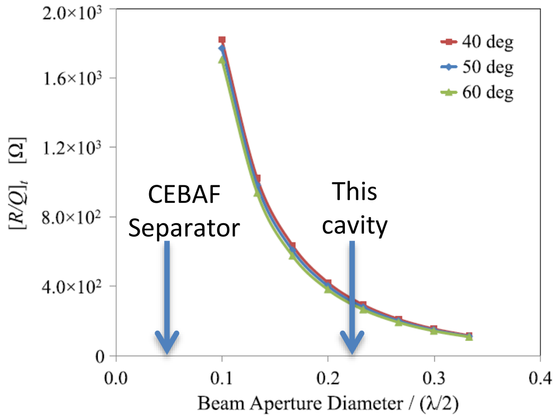
Why a Superconducting Cavity?

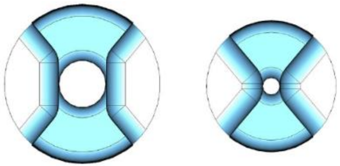
- Normal conducting cavity options
  - Looked into copper 4Rod and RF Dipole options
  - Normal conducting 4Rod specs:

Resonant frequency:	650 MHz
Deflecting voltage:	0.3 (0.6) MV
Shunt impedance:	917 Ω
Geometry factor:	79 Ω
$R_{\perp}R_s$:	$7.2 \times 10^4\ \Omega^2$
RF power dissipation:	8.3 (33) kW
Peak local dissipation:	>100 W/cm^2

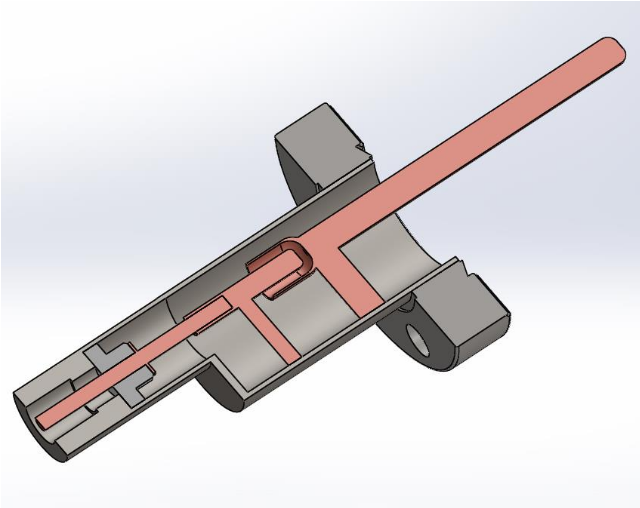


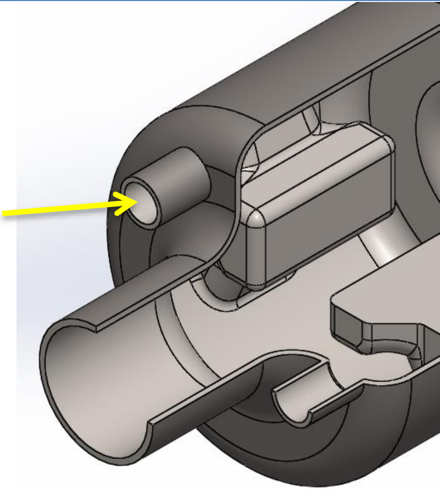
- Main issue is the shunt impedance vs. aperture
  - S. U. De Silva and J. R. Delayen, PRST-AB **16**, 012004 (2013)



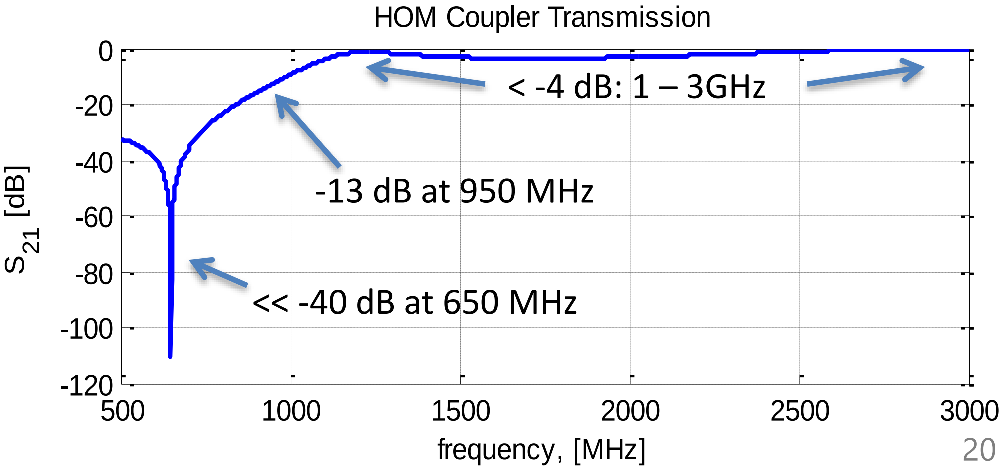


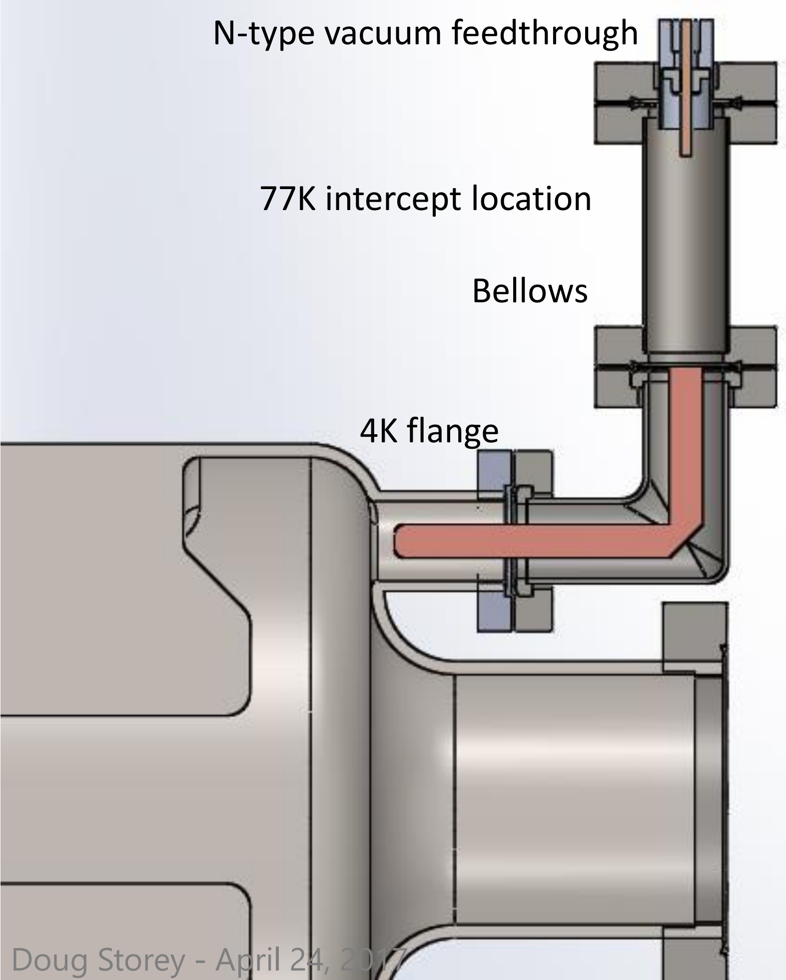
- Coaxial antenna
  - 50Ω transmission to room temperature load
  - 24mm OD, 6mm ID
  - Kyocera N-type feedthrough



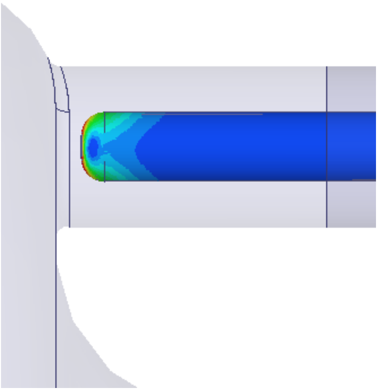


- Operating mode filter
  - $Q_{ext} > 10^{11}$ and < 1 mW extracted from operating mode
    - S_{21} < 40dB for 650 ± 40 MHz
  - Tuning of notch filter will be completed before assembly

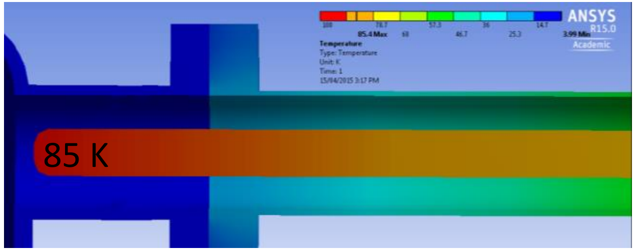


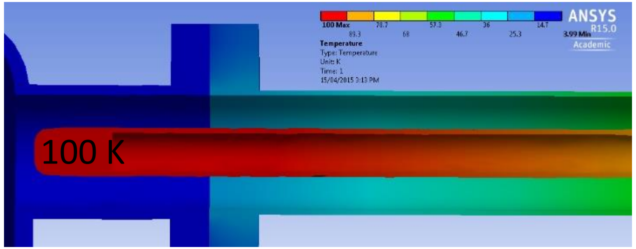


- Coaxial input coupler on end of cavity
  - 24 mm OD, 50Ω fixed coupling
    - $Q_{ext} = 3 \times 10^6$
  - Dynamic power loss on tip of < 2 W
  - Max temperature of tip ~ 85-100 K



Power Distribution





- Radiative heat transfer to cavity < 1 mW

Steady State Input Power

- Active beam loading is for electrons passing off axis at the zero-crossing phase
  - i.e. the recirculated beam
- For optimal coupling: $Q_{ext} = 3 \times 10^6$
  - $P_g = 15$ W with no beam loading or microphonics detuning
  - Can reach cavity voltage with $P_g < 200\text{W}$ for 20mA and $\Delta x < 2$ mm and $\Delta f < 100$ Hz