TESLA TECHNOLOGY COLLABORATION MEETING

Argonne NATIONAL LABORATORY

FABRICATION AND TREATMENT OF QUARTER-WAVE, HALF-WAVE AND SPOKE-LOADED RESONATORS

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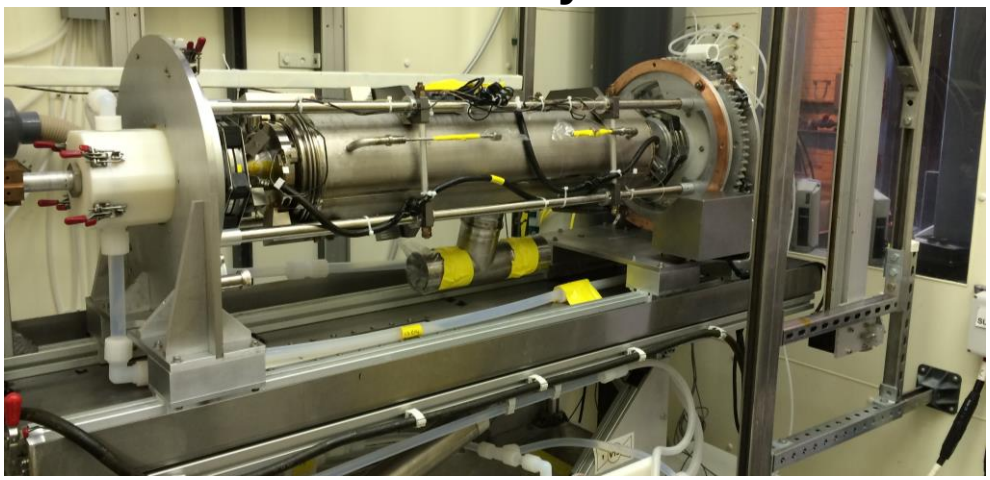
26 June 2018
Argonne, Illinois 60439

ACKNOWLEDGEMENTS

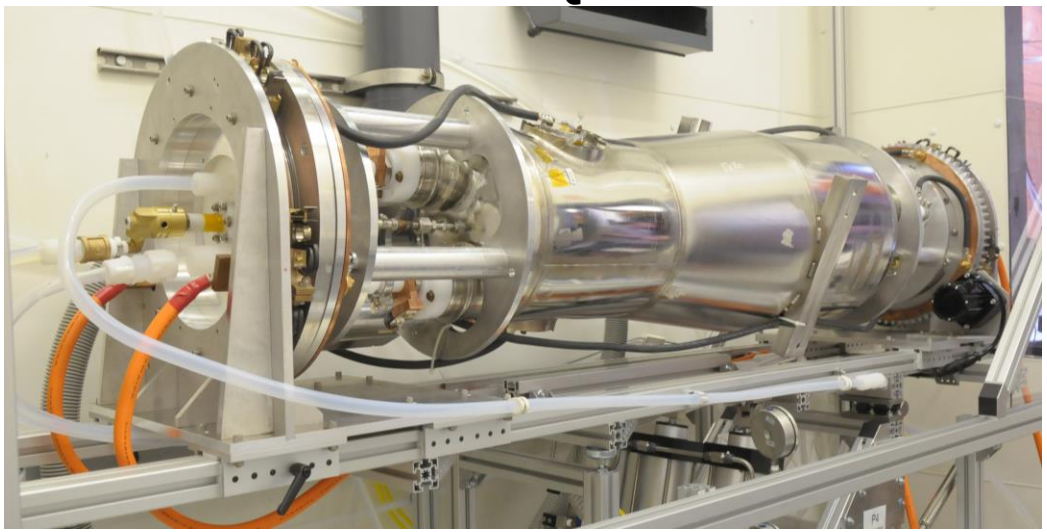
People who deserve more credit than they receive.

- The TTC Collaboration,
- Mike Kelly, Mark Kedzie, B. Mustapha and Tom Reid (ANL),
- Jean Delayen and HyeKyoung Park (ODU/JLAB),
- Matt Fraser (CERN),
- Chris Compton (MSU-FRIB),
- Naruhiko Sakamoto and Kenji Suda (RIKEN),
- Robert Laxdall and Zhongyuan Yao (TRIUMF),
- Jung Hoe Chun and Dong-O Jeon (RAON),
- Leonardo Ristorri (FNAL), and
- Yuan He and Hao Guo (IMP-ADS).

1.3 GHz TESLA Style 9-cell EP



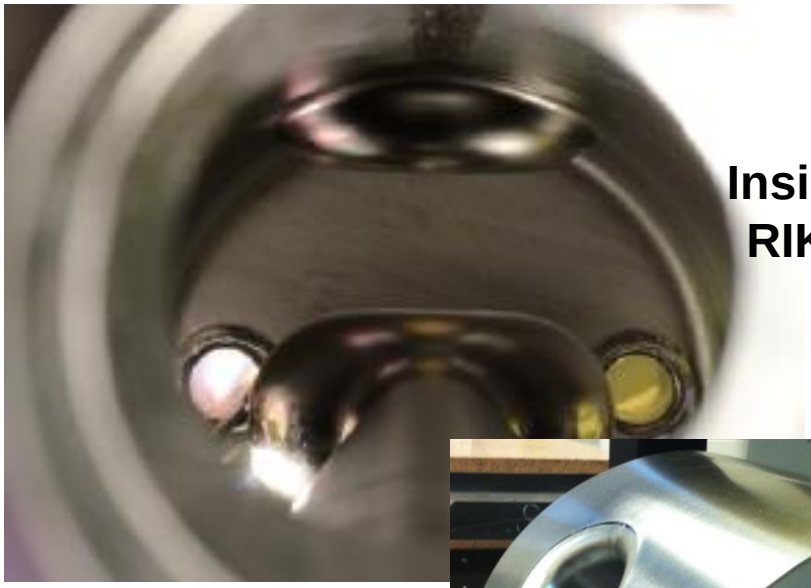
72.75 MHz QWR EP



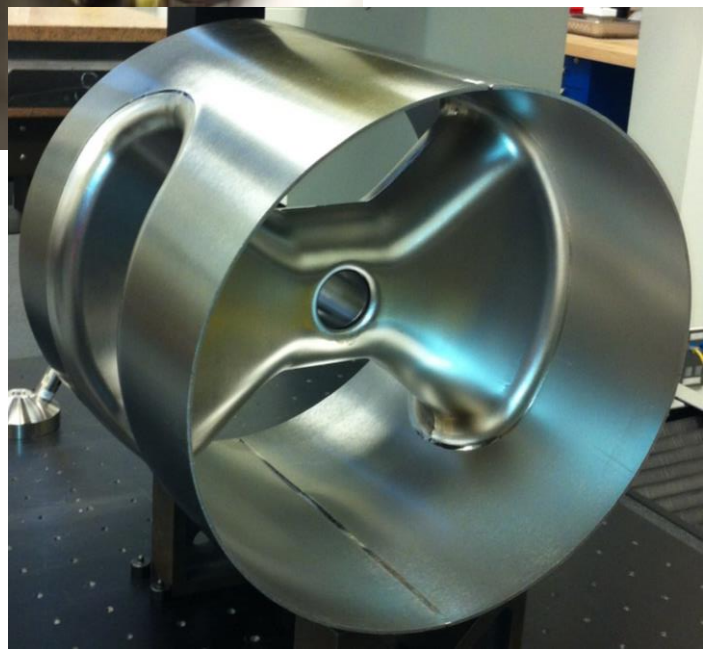
OUTLINE

TEM-class cavity fabrication and processing

- **Fabrication:**
  - **design, and**
  - **practical applications.**
- **Tuning.**
- **Processing:**
  - **methods, and**
  - **results.**
- **Quick summary and personal thoughts.**



Inside View of RIKEN QWR



ODU Spoke

H. Park & J. Delayen (ODU) LINAC'14
N. Sakamoto (RIKEN) et al SRF'17

QWR, HWR AND SPOKE RESONATOR DESIGN

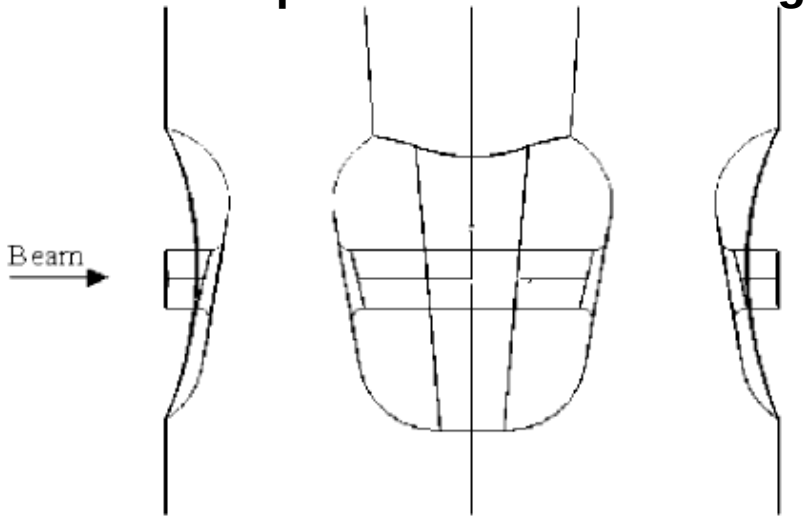
TEM-class cavity complexity

- **Optimize the standard parameters: E_{peak}, B_{Peak}, G, R_{sh}/Q, etc.**

- **In parallel with:**
  - **Beam steering,**
  - **Cleanability,**
  - **Ease of etch/polish,**
  - **Complexity of fabrication, and**
  - **manufacturing limitations.**

- **Summary, integrate the:**
  - **EM design,**
  - **Beam dynamics,**
  - **Manufacturing and Processing**
  - **Cryomodule design.**

Tilted Drift Tube Faces
To Compensate Beam Steering



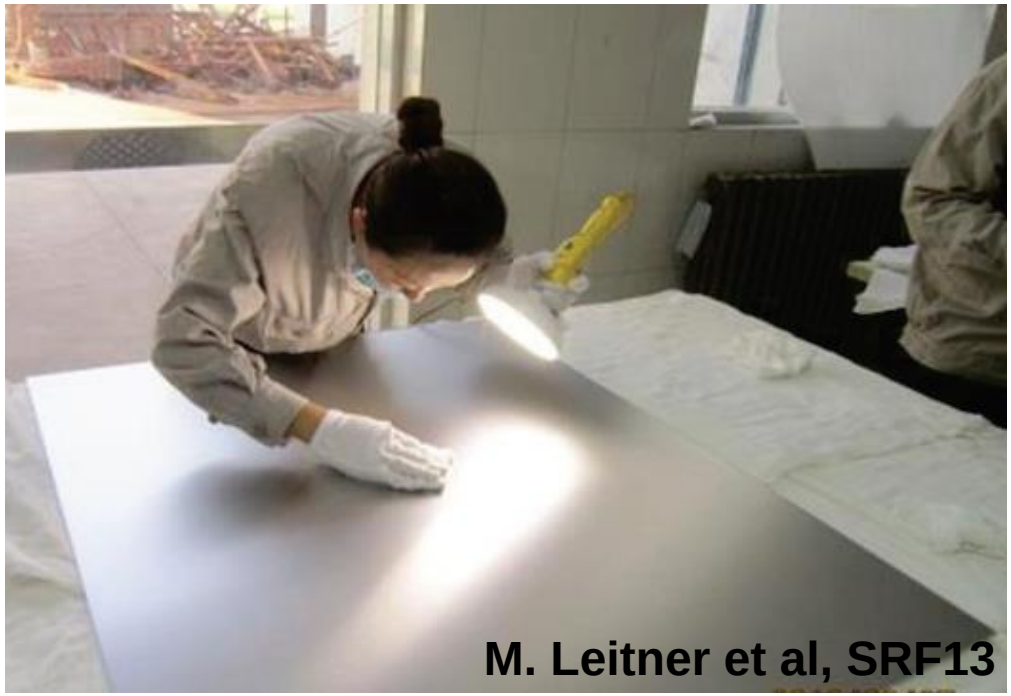
P. Ostroumov et al PRST-AB 4 110101 2001
A Facco and V. Zviagintsev PAC'01
M. Fraser et al PRST-AB 14 020102 2011
B. Mustapha et al IPAC'12
P. Berutti et al IPAC'12

FABRICATION

Introduction

- Design strongly influences fabrication outcome.
- Many trades offs between cost and complexity.
- Defects are caused by fabrication:
  - material,
  - forming,
  - machining,
  - welding,
  - handling,
  - measuring/tuning, and
  - processing.

FRIB Nb Inspection @ Vendor



Nb Inspection @ ANL

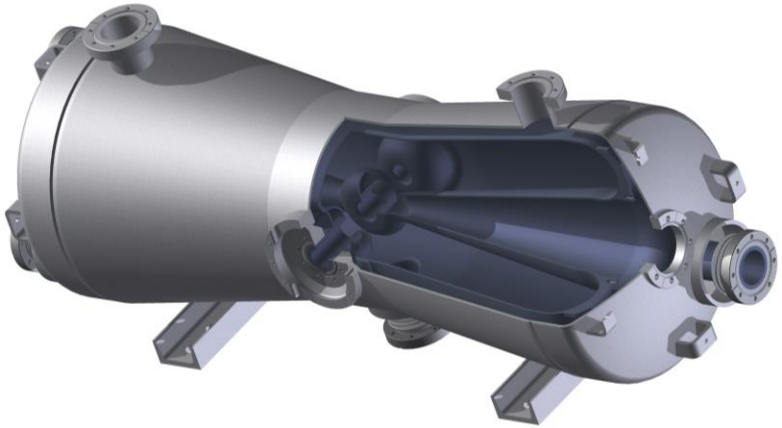
RESONATOR DESIGN - I

What are QWR, HWR and Spoke-Loaded Resonators

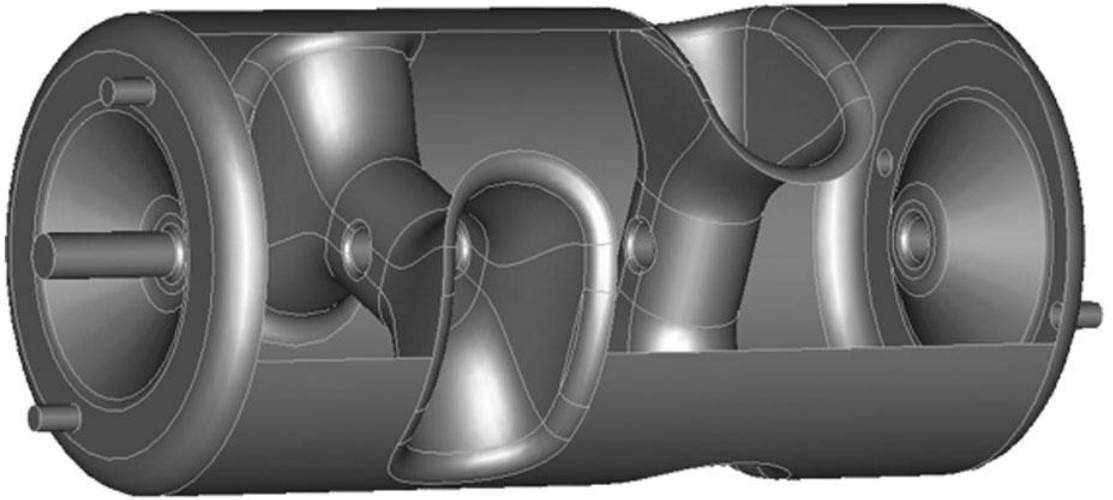
FRIB Quarter-Wave Resonators (QWR)

C. Compton et al SRF'15

Half-Wave Resonator (HWR)



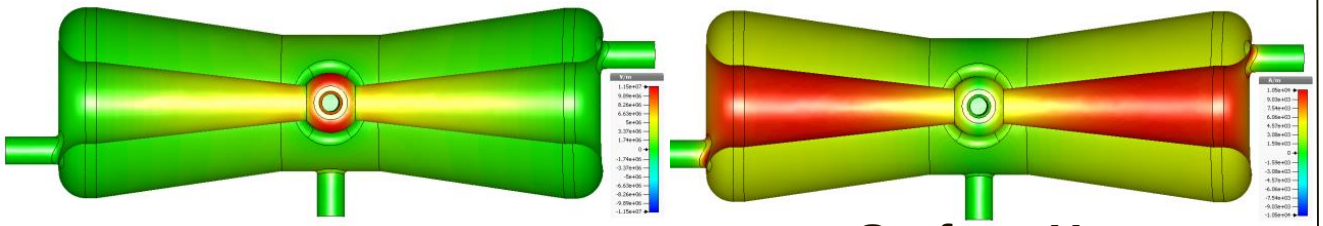
ODU β = 1 Spoke-Loaded Resonator



C. Hopper and J. Delayen PRST-AB 16, 102001 (2013)

RESONATOR DESIGN - II

Half-Wave Resonator

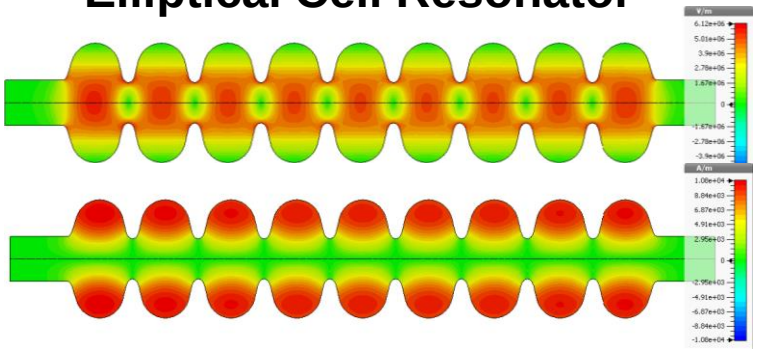


Surface-E

Surface-H

TEM

Elliptical Cell Resonator

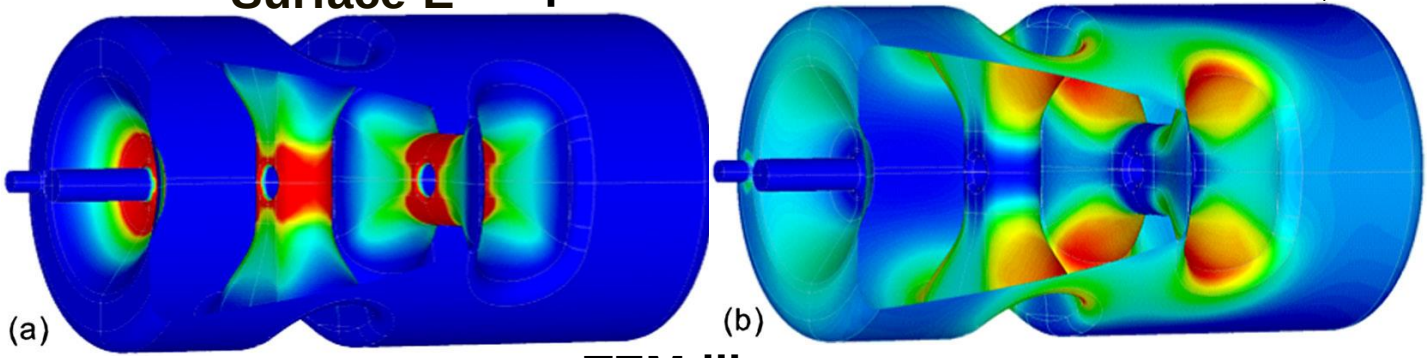


Volume-E

Volume-H

TM_{010}

Spoke Resonator



Surface-E

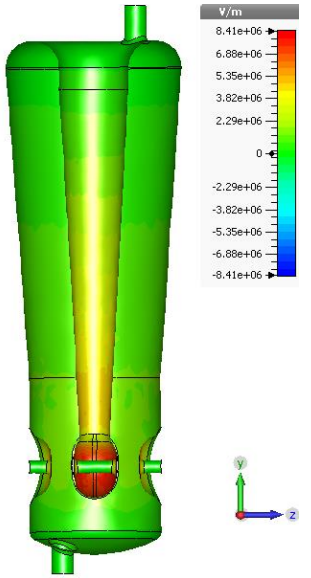
Surface-H

(a)

(b)

TEM-like

Quarter-Wave Resonator



Surface-E

Surface-H

TEM

FORMING - I

Try not to add anything to the Nb

- Forming well understood for decades.
- Forming Nb parts via deep drawing with strain rates > 180%.
  - Electrohydraulic forming may go farther.

Balloon Spoke Cavity @ TRIUMF

MSU Toroids with Ports

FNAL SSR1 End-Wall Formed From a single Nb Sheet

FORMING - II

Reduce weld area on high field surfaces

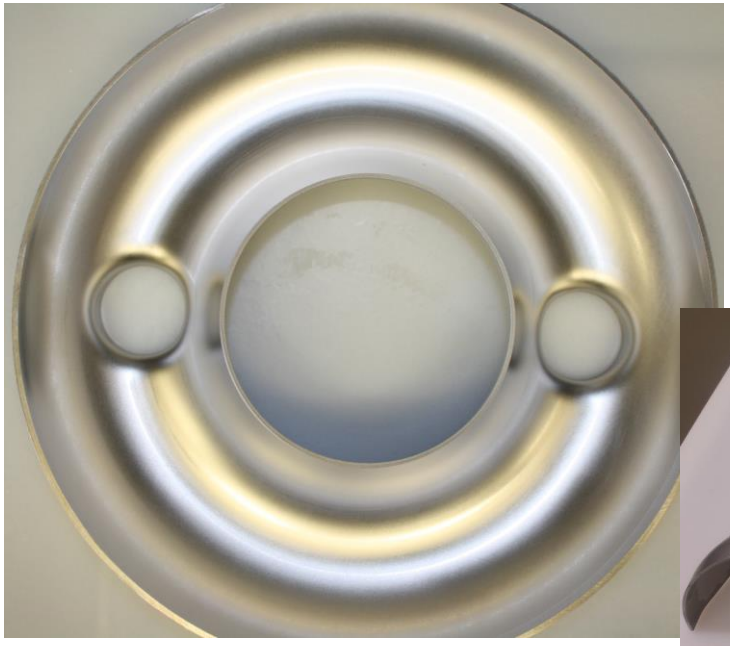
- Design for easy of welding.
- Branch pull or burring (RIKEN) to form ports.

TRIUMF Balloon Spoke

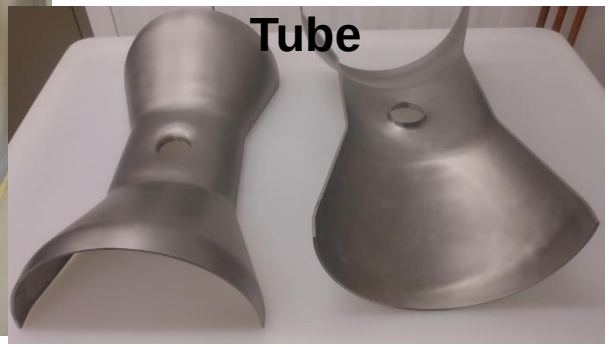
ODU 500 MHz Spoke

RIKEN QWR Ports via Burring

Toroid with Branch Pulls



MSU Formed Beam Tube



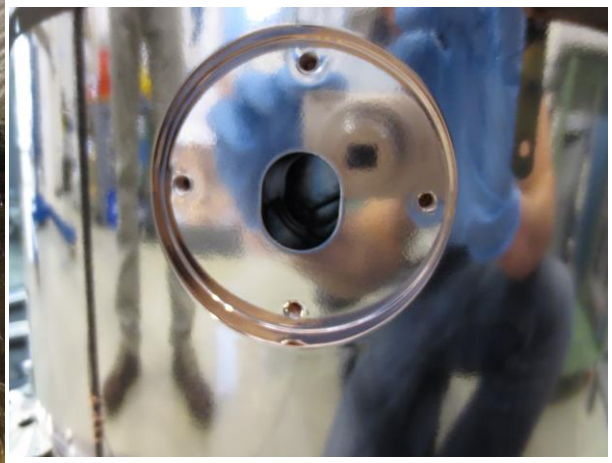
MACHINING

Reduce weld area on high field surfaces

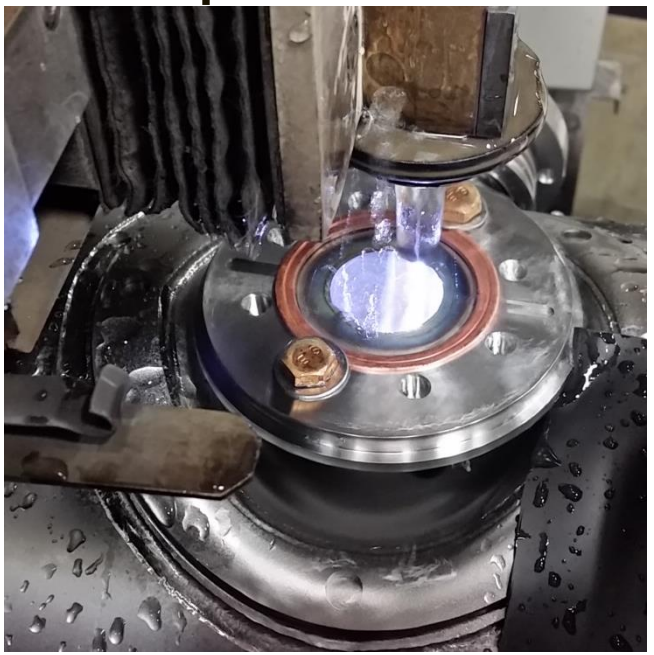
- QWR, HWR and Spoke fabrications create complicated geometries.
- Machining gets you to the end product.
- Conventional and EDM are employed.
- Must be careful to not contaminate weld seams with tooling/debris

Toroid EDM

HIE-ISOLDE QWR
off set beam aperture



Beam Aperture Wire-EDM



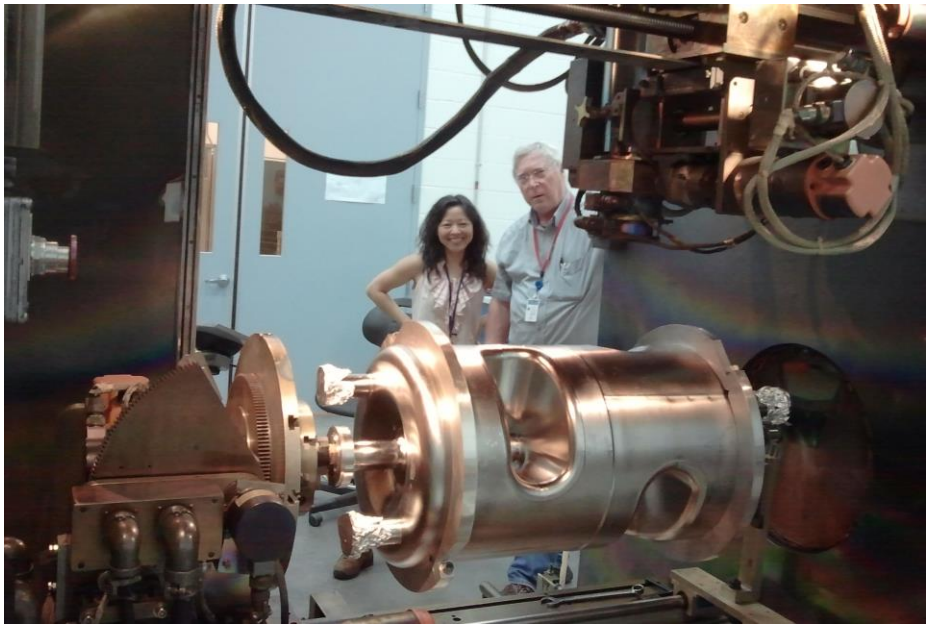
Beam Aperture Wire-EDM

WELDING

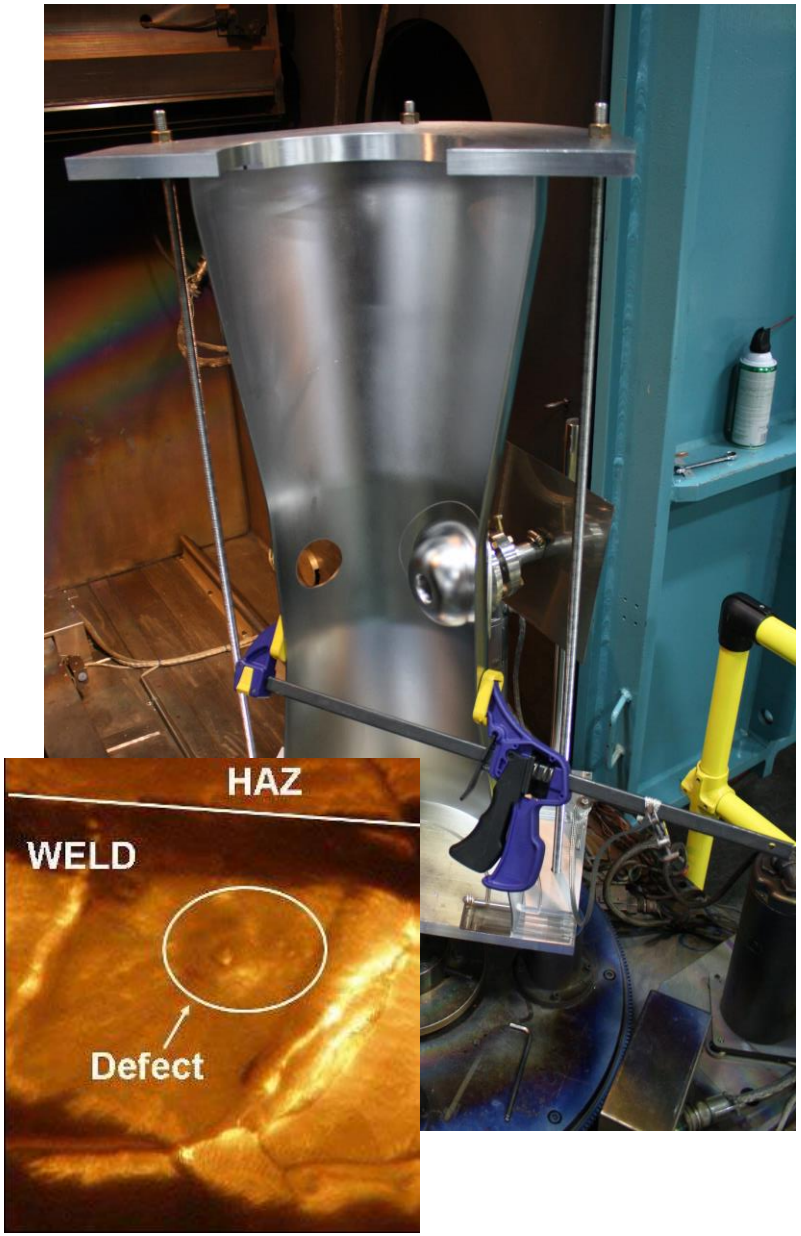
Electron Beam Welding

- 100% Electron Beam Welding.
- Frequently need multi-axis welds:
  - MSU-FRIB Resonators,
  - ODU Spoke Resonators, and
  - ANL Resonators.

Double Spoke EBW @ JLAB



Reentrant Nose Welding

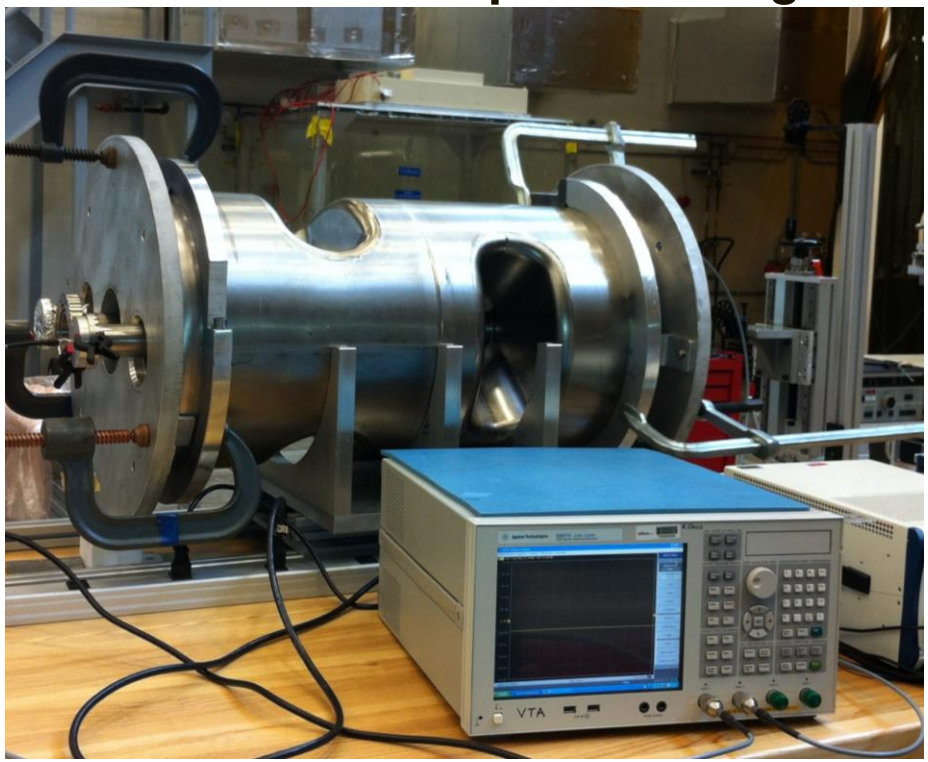


TUNING

Full Cavity Mock-Ups

- QWR, HWR and Spoke resonator tuning generally requires machining; parts are not mass produced.
- Same considerations as before.

ODU Double Spoke Tuning



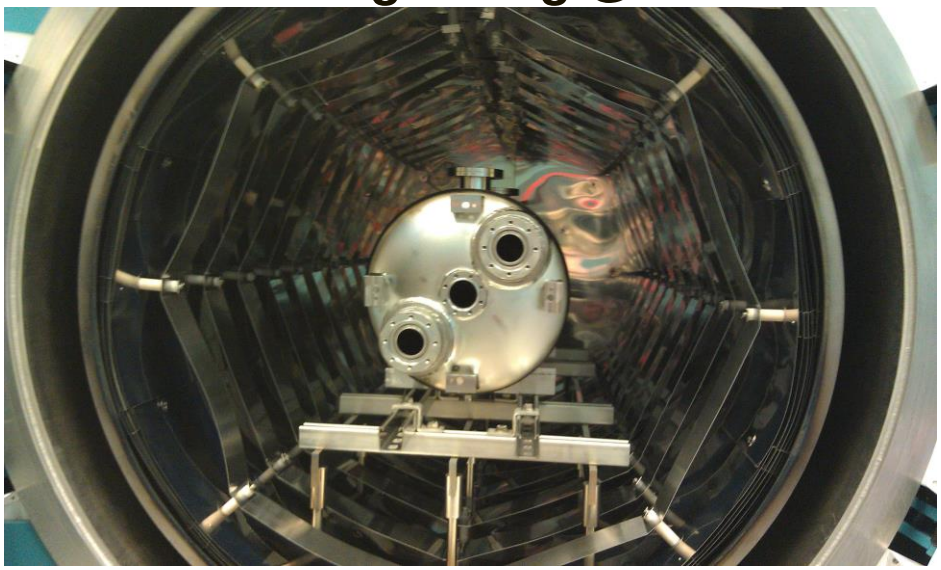
HWR Tuning

PROCESSING

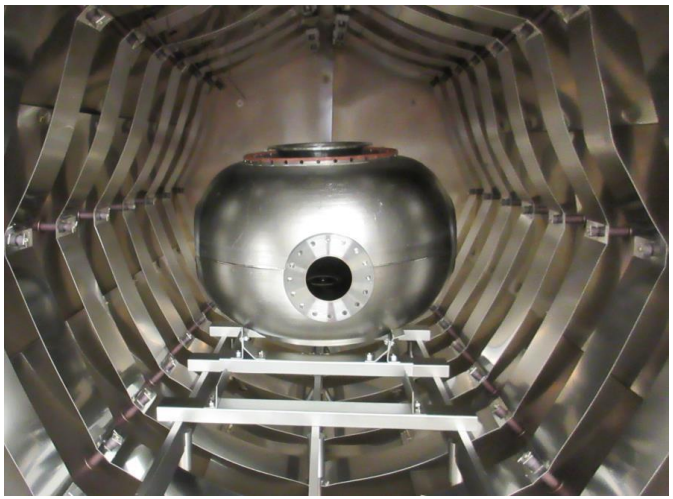
Make the cavity pretty.

- Ultrasonic cleaning, hydrogen degassing, BCP/EP, and HPR.
- Hydrogen degassing is almost universally employed for these cavities @ 600^{0}C for 8-12 hours.
- EP or BCP? Cost and experience driven..
- High Pressure Rinsing (HPR).

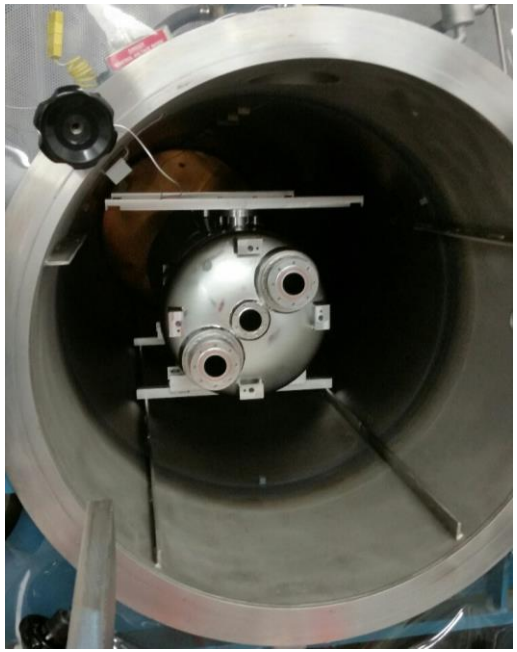
HWR H-Degassing @ FNAL



TRIUMF Spoke H-Degassing



H-Degassing @ BNL



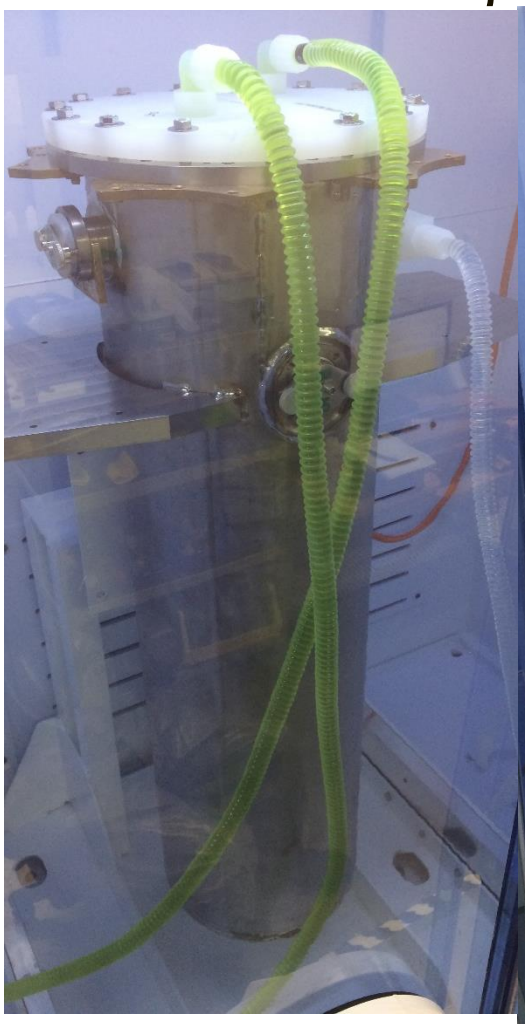
BUFFERED CHEMICAL POLISHING

Smooth all over.

- BCP gives good results on QWR, HWR and spoke loaded resonators.
- See for example
  - FNAL's recent work on spoke cavities: A. Sukhanov et al SRF'13.
  - MSU's production efforts: T. Xu et al SRF'17.

RIKEN QWR After BCP

FRIB $\beta = 0.29$ BCP



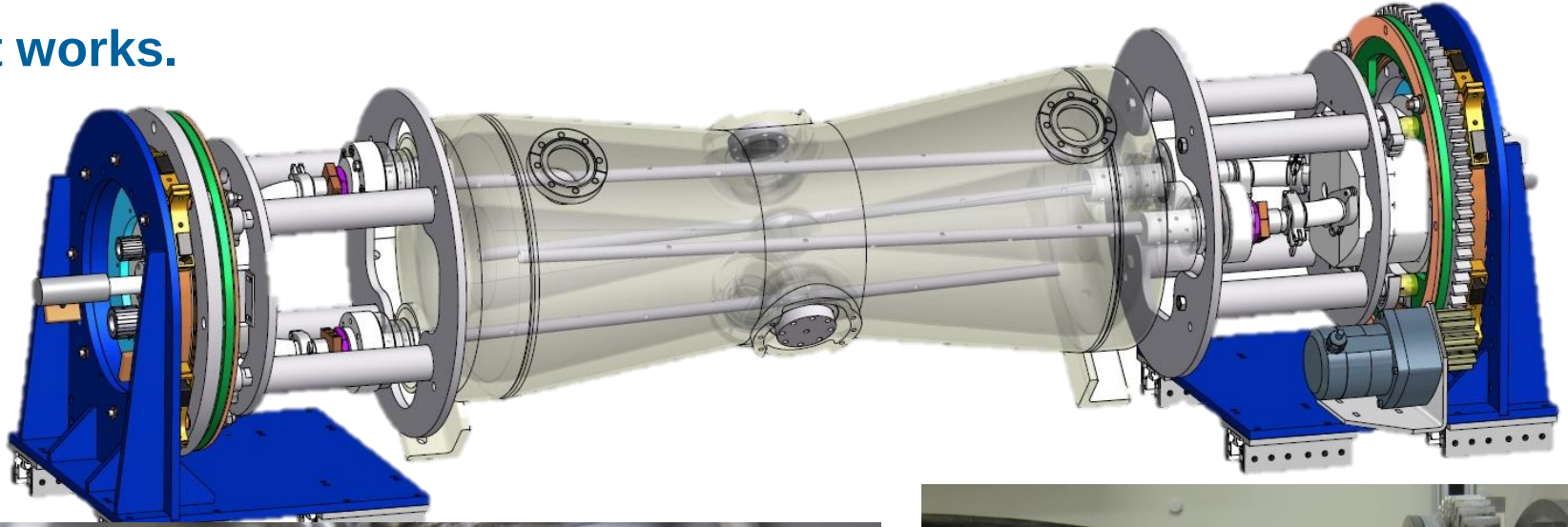
ELECTROPOLISHING

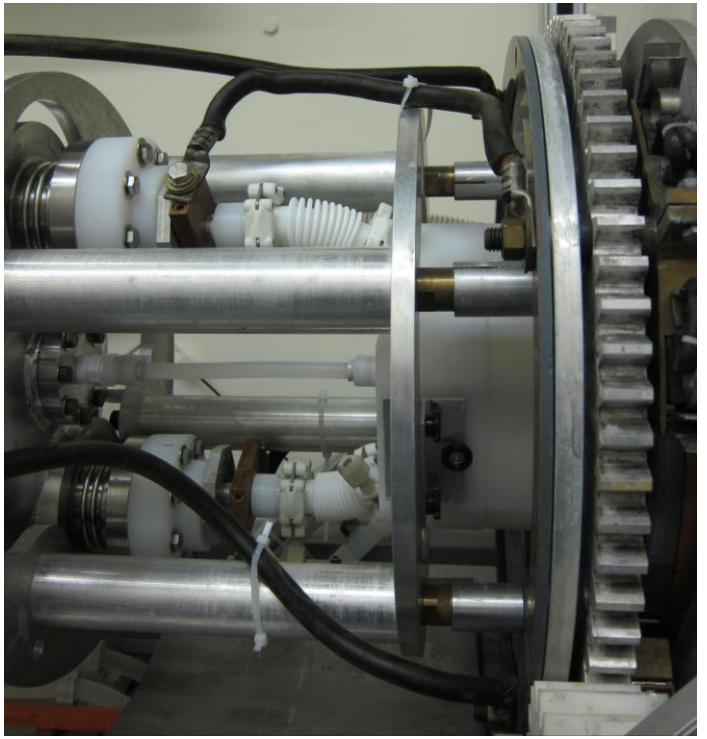
In use at ANL since the 1970s.

- All polishing is done after fabrication is finished.
- Cooling water flow through space between helium jacket and Nb cavity.
- Unique Argonne Low-Beta Cavity EP Tool.
  - S.M. Gerbick et al, SRF'11.
  - M.P. Kelly et al, SRF'11.
- Would like to expand the application of EP in QWR, HWR and Spokes!

ELECTROPOLISHING - II

How it works.



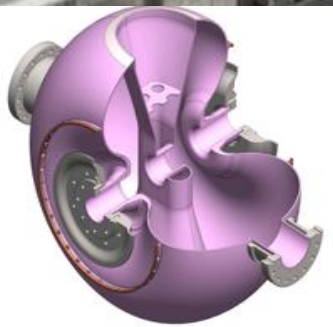


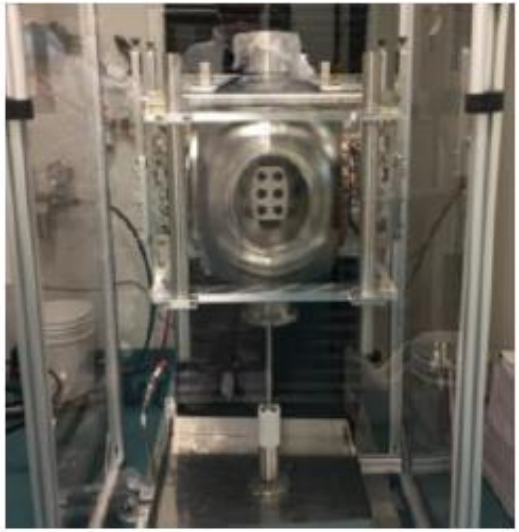
HIGH PRESSURE RINSING

Get rid of the particulates (most of them).

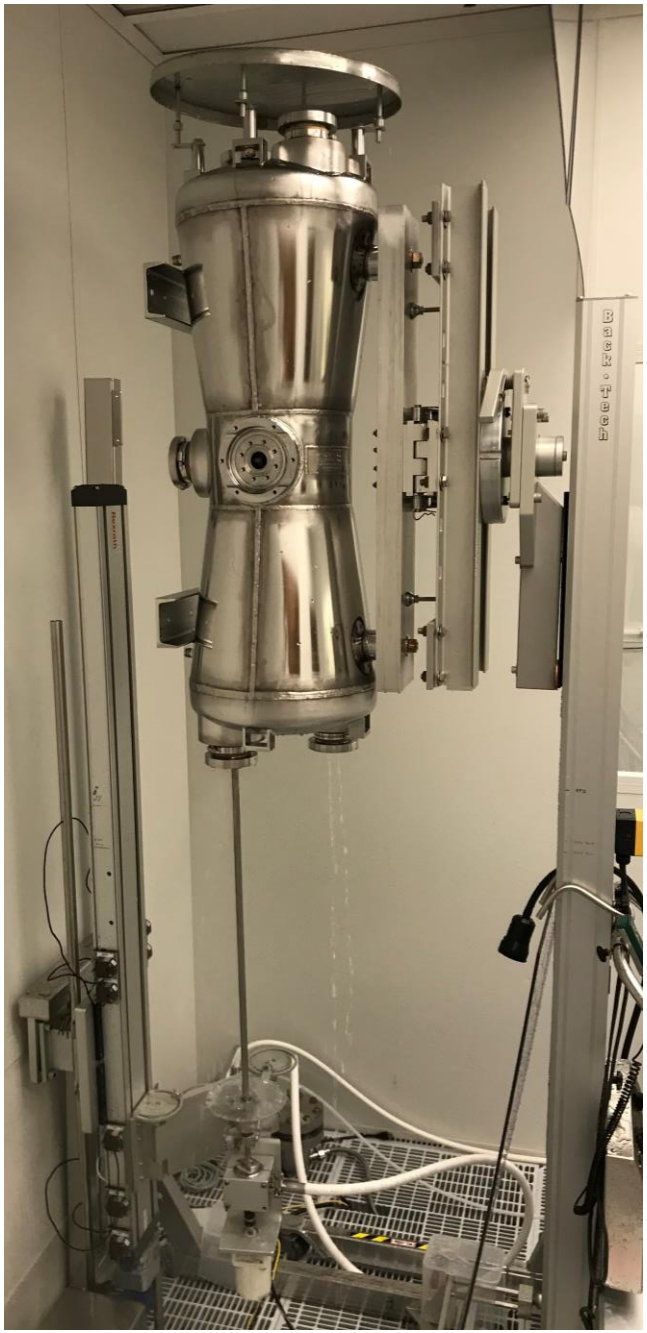
- **Design cavities for fluid flow.**
- **Spoke cavities are generally HPRed in 2 orientations:**
  - **TRIUMF & ANL.**
- **HPR varies greatly between labs.**

TRIUMF Balloon Spoke HPR



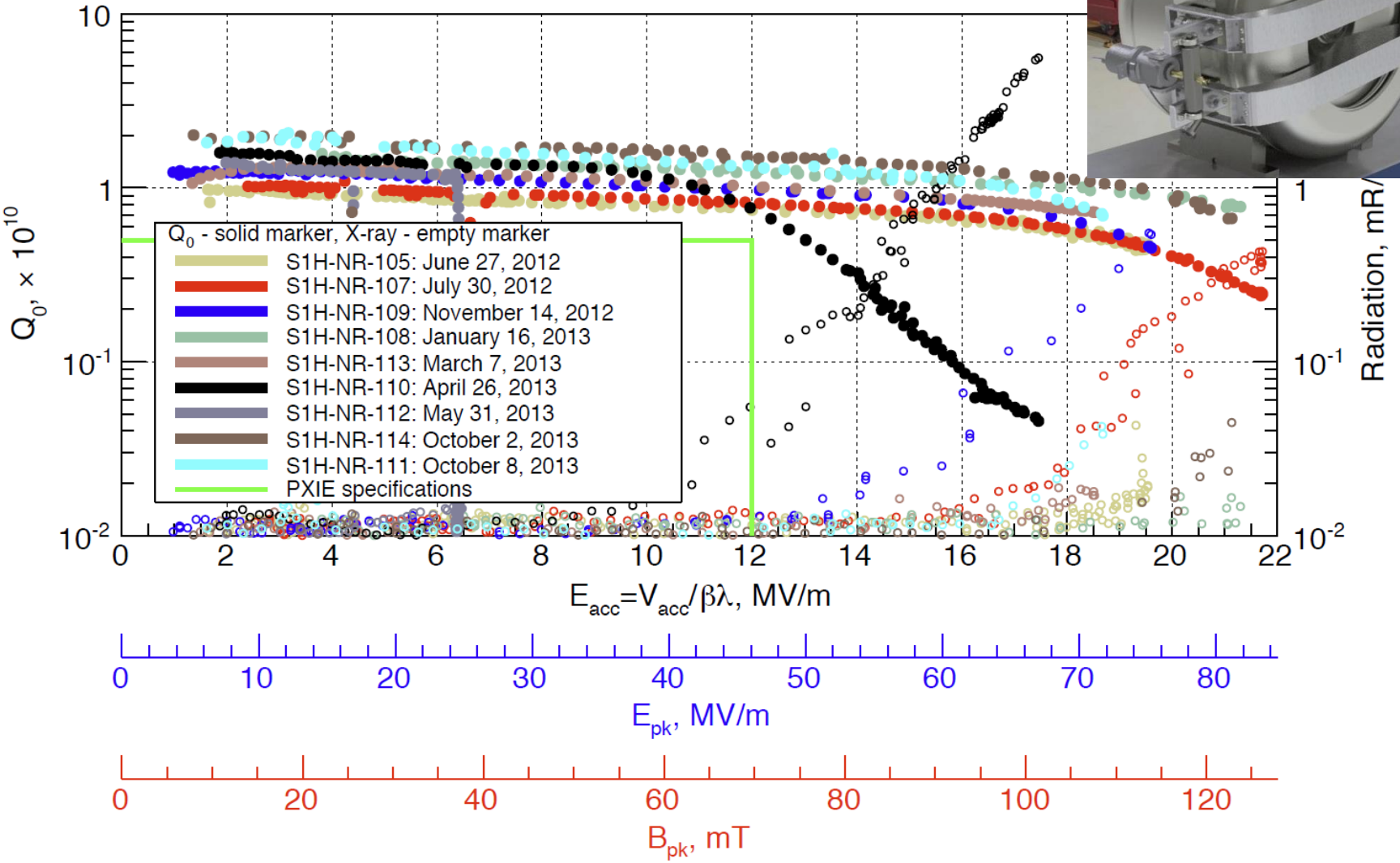


Z. Yao et al (TRIUMF)
SRF'17



BCP TREATED RESONATORS

FNAL 325 MHz SSR

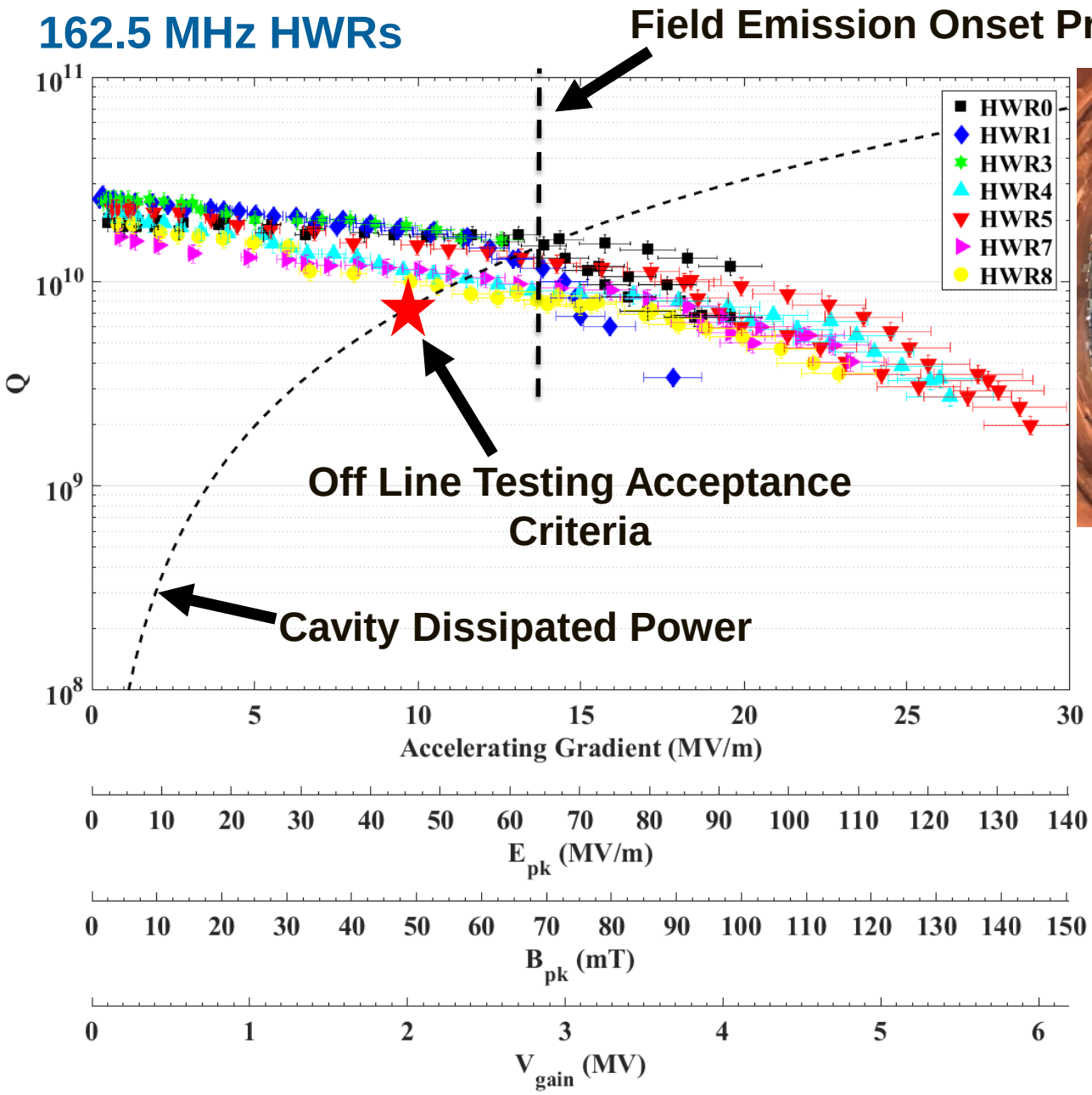


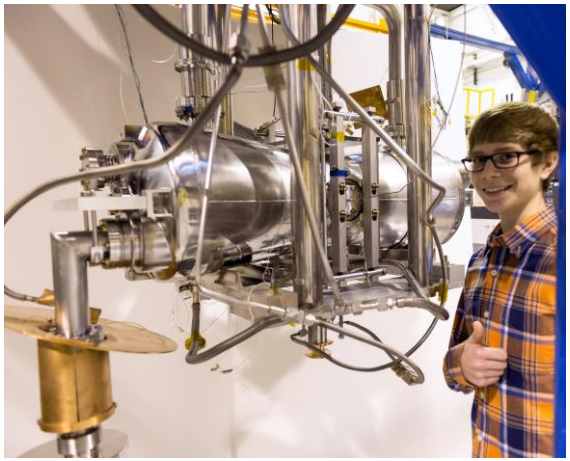
L. Ristori et al., SRF09; T. Nichol et al., PAC13.

A. Sukhanov et al. LINAC14.

ARGONNE HALF-WAVE RESONATOR PERFORMANCE

162.5 MHz HWRs





Argonne NATIONAL LABORATORY

SUMMARY

A quick recap

- **QWR, HWR and Spoke-Loaded Resonators provide a rich and interesting parameter space to explore.**
- **Many different labs are working on this problem: different applications, new and unique approaches, demanding operating conditions.**
- **Cavity fabrication and processing techniques continue to evolve.**
- **Performance rivals the TTC elliptical cell resonators in some cases.**

RIKEN QWR